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THE METHODS OF ORGANIC CHEMISTRY

A LABORATORY MANUAL

BY

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PREFACE

This outline provides material for a laboratory course in organic chemistry. The experimental parts include a general survey of the field based upon preparations of typical compounds and a detailed study of type reactions based upon a system of qualitative analysis. A discussion of the physical principles involved in the laboratory work precedes the experimental sections.

The book is designed to meet the requirements of either the usual short course in organic preparations, or of a full-year course. Part I and experiments selected from Part II constitute the subject matter for a half-year course. The system of qualitative analysis as outlined in Part III constitutes material for a second half-year's work. Some of this may be substituted by quantitative analysis as outlined in Part V, in which the classical processes are briefly described. The qualitative analysis has as its primary purpose not the identification of individual compounds, but the detection of characteristic groups or radicals and the development of a thorough understanding of class reactions. The laboratory directions for this part of the work are accompanied by discussions of the reactions involved in the tests and summaries of other characteristic reactions.

The authors are glad to acknowledge their indebtedness to standard manuals dealing with organic preparations and with methods of analysis. Mulliken's "Identification of Pure Organic Compounds" and Kamm's "Qualitative Organic Analysis" have been especially useful.

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THE METHODS OF ORGANIC CHEMISTRY

PART I. MECHANICAL OPERATIONS

DISTILLATION

The distillation of a liquid involves its conversion to the vapor state and the condensation of the vapor back to the liquid state. Such a process can be utilized to transfer a substance from one vessel to another or to separate a volatile substance from a relatively nonvolatile one. The process involves the consideration of three factors: (1) the conversion of the substance to the vapor state, (2) the transference of the vapor, and (3) the condensation of the vapor back to the liquid (or sometimes solid) state.

Conversion of a pure substance from liquid to vapor. At the surface of a liquid the process of volatilization is continuous and represents the escape of the faster-moving molecules from the liquid phase. The number of molecules that escape per second will depend upon the nature of the molecule (kind of substance) and the average velocity of the molecules (the temperature). If the cohesive forces between the molecules of a liquid are slight, there will be little hindrance to the escape of a molecule; but if the cohesive forces are strong, a molecule must attain a velocity (kinetic energy) very much higher than that of the average to effect escape from the liquid phase. An increase in temperature increases the kinetic energy of the molecules, and hence increases the rate of volatilization. Since the molecules which escape from the liquid have a higher energy content than those remaining, the liquid after partial evaporation is cooler than before; and in order to maintain the same temperature and rate of volatilization, heat must be applied to the liquid. The heat required to accomplish this is the heat of vaporization.

Vapor pressure of a pure substance. If a liquid is placed in a closed vessel, the concentration, or partial pressure, of the vapor will increase until the rate of condensation equals the rate of volatilization. The rate of condensation will depend upon the kind of substance, the number of impacts of the molecules on the surface per second, and the velocity of the molecules.

For a given substance at a given temperature, therefore, an equilibrium will become established between the rates of volatilization and condensation when a certain definite pressure of the vapor is reached. At this pressure both processes proceed at the same rate, and *the pressure of the vapor at equilibrium is called the vapor pressure of the substance.* An increase in temperature causes a greater increase in the rate of volatilization than in the rate of condensation. Therefore, in order to maintain equilibrium under an increased temperature, an increased pressure is necessary. *At each temperature there is a corresponding vapor pressure.* Fig. 1 shows the changes in vapor pressure with the changes in temperature for several pure substances.

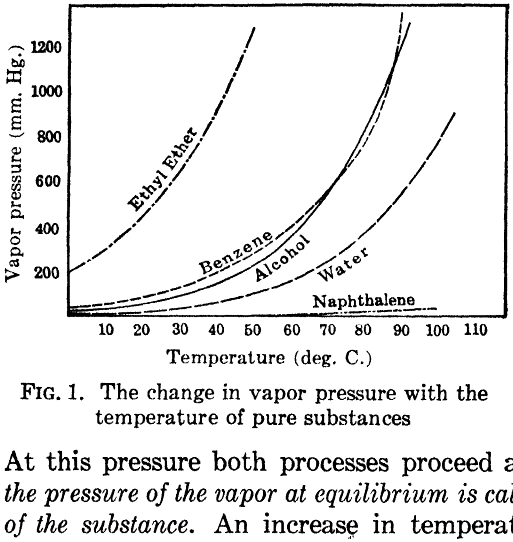

FIG. 1. The change in vapor pressure with the temperature of pure substances

The vapor pressure of a substance is determined by a dynamic equilibrium and is the result of the relative rates of two opposing reactions — volatilization and condensation — at the surface of the substance. The actual or specific rate of either one of the reactions is not alone sufficient to determine the vapor pressure. It is conceivable that of two substances — a solid and a liquid — the solid might have the higher vapor pressure. Its rate of volatilization might be one tenth of the rate of volatilization of the liquid, but the rate of condensation of the vapor of the solid might be one twentieth of that of the vapor of the liquid; and in order that the two reactions might balance in each case, the vapor of the solid would have to be twice as concentrated as the vapor of the liquid.

Correspondingly anything that affects the rate of one reaction more than that of the other must change the vapor pressure. Dissolving salt in water lowers the rate of volatilization but does not materially affect the rate of condensation. Hence the concentration of vapor (the vapor pressure) necessary to offset the volatilization is lowered. A layer of kerosene on the surface of water retards both reactions in the same ratio, and the vapor pressure of the water is unaltered; but the time required to reach equilibrium is longer.

Imagine a beaker nearly full of water and provided with a tight cover. The gas space quickly becomes saturated with water vapor. If now the cover is removed without disturbing the air, the water vapor slowly diffuses into the room, thereby decreasing the concentration of water vapor immediately over the liquid, and more liquid evaporates. Since the diffusion is slow, the evaporation is slow. If the air and the vapor at the surface of the water are removed by means of a fan, the concentration of water vapor at the surface is very rapidly decreased, so that the rate of evaporation is practically equal to the rate of volatilization; that is, the rate of condensation is zero. Rapid evaporation may be brought about also by diminishing the air pressure, so that the diffusion of water vapor from the region near the surface is more rapid (see Methods of Drying, p. 42). In none of these operations is the vapor pressure of the liquid altered. Fig. 1 indicates that for a pure substance the vapor pressure depends only on the temperature. At a given temperature the vapor pressure may be altered appreciably only by dissolving something in the liquid, thereby changing its concentration. Pressure on a liquid has but a very slight effect on the vapor pressure.

Vapor pressure and boiling point of a pure substance. Volatilization and boiling differ in that the former takes place at the surface of the liquid at all temperatures and pressures, whereas the latter involves the formation of bubbles of vapor within the liquid. The pressure within such a bubble is equal to the hydrostatic pressure at that point, which in turn is determined by the atmospheric pressure on the liquid and the depth of the bubble beneath the surface. Since the bubble is pure vapor (not to be confused with the formation of small bubbles of dissolved air or any other gas that is driven out by heating), it can exist only at or above the temperature at which the vapor pressure of the liquid is equal to that pressure. The boiling temperature, then, would vary with the depth as well as with the atmospheric pressure. The boiling point of any liquid, however, is defined as *that temperature at which the vapor pressure of the liquid is equal to atmospheric pressure.* In practice, therefore, a thermometer immersed in a boiling liquid does not give the true boiling point, owing to two effects: (1) increased pressure due to the bubbles forming at a finite distance beneath the surface, and (2) superheating of the liquid. The method for determining the true boiling point is discussed later (see page 35).

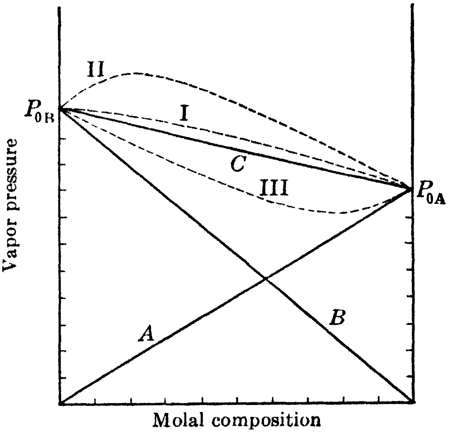

FIG. 2. Vapor-pressure-composition diagram for a binary solution

Vapor pressure of a solution. The vapor in equilibrium with a homogeneous mixture of substances (a solution) will contain the vapor of each component, the relative amounts (partial pressures) of each being dependent on the chemical nature of the components, the relative volatility of each, the amount of each present in the solution, and the temperature. Thus, for a series of solutions of two liquids, at any given temperature, a diagram showing the relation between vapor pressure and composition would appear as in Fig. 2, where the molal composition is plotted on the horizontal axis and the vapor pressure on the vertical axis. Curve A represents the partial vapor pressure of component A in an ideal mixture; curve B, that for component B; and curve C, the total vapor pressure of the mixture. The relationship expressed by curve A or curve B (Fig. 2) can be given in the form of an equation (Raoult's law) for each component of a solution of any number of components,

$$P_A = P_{0A} \cdot \frac{N_A}{N_A + N_B + N_C + \cdots},$$

where P_A is the partial vapor pressure of A, P_{0A} the vapor pressure of pure A at the same temperature, and N_A, N_B, N_C, etc. the number of mols of each substance present. This is, however, an ideal case, and in practice it represents only an approximation, since the individual vapor pressures may deviate so widely from the ideal case as to cause the total vapor pressure to pass through a maximum or minimum (curves II, III, Fig. 2). Solutions of benzene and toluene correspond closely to the ideal case (curve C). Many solutions deviate slightly (curve I). Solutions of alcohol in water and of hydrogen chloride in water correspond to the types represented by curves II and III respectively, where at some concentration the total vapor pressure of the solution is either greater or less than the vapor pressure of either pure component at the same temperature.

The vapor pressure of a pure substance is lowered by the addition of either a solid or a liquid solute. If, then, the solute is nonvolatile, the total vapor pressure of the solution will be less than that of the pure solvent at the same temperature; but if the solute is volatile, the decrease in vapor pressure of the solvent *may be* more than compensated by the vapor pressure of the solute, and the solution may have a total vapor pressure greater than that of the solvent alone at the same temperature. Insoluble substances do not affect the vapor pressure of the solvent.

Effect of solutes on the boiling point. If salt is added to water boiling at 100° C., the vapor pressure of the water is lowered, and in order to maintain the boiling, or maintain the vapor pressure at atmospheric pressure, the temperature must be raised. On the other hand, if alcohol is added, the total vapor pressure of the mixture will equal atmospheric pressure below 100° C., and the boiling point will be lowered. The addition of sand or other nonvolatile and insoluble material would have no effect on the boiling point. The addition of benzene or other volatile, insoluble liquid would not affect the vapor pressure of the water, but the heterogeneous mixture would boil at that temperature at which the sum of the vapor pressures of pure benzene and water equaled atmospheric pressure (see Steam Distillation, p. 15).

In general, then, we may say that a nonvolatile impurity raises the boiling point of a liquid; that a volatile impurity may either raise or lower the boiling point, according to the relative volatility and the amount and nature of the substance; and that either a pure substance, a solution, or a mixture will boil when the total vapor pressure equals atmospheric pressure.

Distillation, or the transference and condensation of vapor. The transfer of vapor, such as steam, is usually accomplished by maintaining a difference of pressure in different parts of the system. Under these conditions the vapor flows from the point of higher to that of lower pressure. In an ordinary distillation the liquid is heated slightly above its boiling point. The pressure of the vapor is then greater than the atmospheric pressure, and the vapor flows out of the containing vessel. By means of a cooling system, or condenser, the temperature of the vapor may be lowered and the vapor pressure reduced to any desired point; this results in the condensation of the vapor back to the liquid.

It is possible to accomplish distillation without boiling. Consider a system, as shown in Fig. 3. The flask *A* contains a liquid, the remaining space contains air at atmospheric pressure. The system is then closed and maintained at room temperature. Eventually the air becomes saturated with the vapor of the liquid at that temperature and the partial pressure of the vapor becomes uniform throughout. If now compartment *B* is cooled, the partial pressure of the vapor in *B* must decrease to conform to the new temperature, and accordingly some of it must condense. The total pressure throughout the system is always uniform, but in the cooler compartment the partial pressure of the vapor is less than that in the warmer compartment; hence vapor *diffuses* to the cooler compartment and condenses. A distillation may thus be brought about at any temperature, but at low temperatures it is obviously very slow. If the air were removed, a real difference in total pressure would exist in compartments *A* and *B*, and diffusion would be replaced by a convection current, the total pressure would fall to the vapor pressure of the liquid at the lower temperature, and the liquid in *A* would boil. This would be essentially a vacuum distillation. The rate of distillation could be increased by passing a current of air through *A* and *B*. If the air became saturated with the vapor of the liquid in *A*, some of the vapor would condense in the cooler chamber *B*, since at the lower temperature the vapor pressure of the liquid is lower. This principle is used in steam distillation of very high-boiling liquids. The steam is passed through the liquid, and after condensation of the mixed vapors the liquids are separated mechanically.

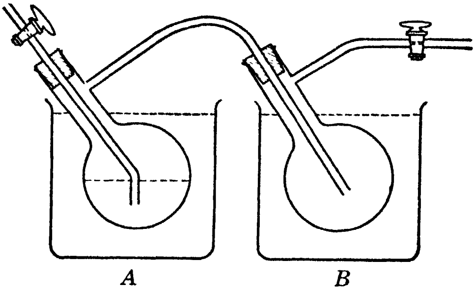

FIG. 3

The same principle holds in the use of a desiccator. Crystals to be dried are placed in a closed vessel which contains some material over which the vapor pressure of water is very small. The pressure of water vapor over the moist crystals varies with the nature of the crystals. For a very soluble substance, such as urea, it would be comparatively low; for a sparingly soluble substance, such as acetanilide, it would be almost that in equilibrium with pure water at the same temperature. If the pressure of water vapor in equilibrium with the dehydrating agent is still lower, however, all the water leaves the crystals; but the rate of drying depends upon the rate of volatilization from the crystals and upon the rate of diffusion, and the rate of condensation depends upon the nature of the dehydrating agent. Tremendous variations may occur in these rates. The same considerations apply in obtaining crystals free from other solvents.

Boiling point and temperature of distillation. If a liquid is distilled from a simple distilling flask (p. 18) with the thermometer in the vapor, the distillation temperature is usually the boiling point of the *distillate.* It is not the boiling point of the liquid residue unless the distillate and residue are identical in composition. The vapor as it leaves the liquid is at the temperature of the boiling point of the liquid (p. 4). As the vapor ascends in the neck of the flask it is cooled and some of it condenses. At this point true equilibrium may exist between the liquid (condensed vapor) and the remaining vapor. If boiling is sufficiently rapid, so that the vapor remains at atmospheric pressure during this partial condensation, a thermometer placed at any point will register the boiling point of the liquid condensed on it at that point. A number of thermometers placed in the flask at different levels will register the same temperature if the vapors condensing at all points have the same composition. If the temperatures differ, however, it means that liquids of varying composition and boiling points are being formed by the condensing vapor.

A constant temperature of distillation will always be obtained when the composition of the distillate remains constant during the distillation.* This is true because the distillation temperature is the boiling point of the distillate, and any one portion of the distillate will boil at the same temperature as any other portion if the distillate is of constant composition; but if the distillate varies in composition, the temperature of distillation must also vary.

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* This may be illustrated by the distillation of a salt solution. The boiling point of the aqueous solution is higher than that of pure water (p. 6), but on distillation only the water vaporizes, and in passing through the flask the vapor is cooled to the condensation or boiling point of pure water. As long as the flask is completely filled with the vapor at atmospheric pressure, and as long as partial condensation has occurred on the thermometer, insuring equilibrium between the liquid and the vapor, the distillation temperature will remain at the boiling point of the pure water distillate, and not at the boiling point of the residue.

The last paragraph can be restated in terms of the vapor in equilibrium with the boiling liquid. If the vapor is the same in composition as the liquid, then liquid and vapor (distillate) remain constant in composition as the distillation proceeds, and a constant temperature of distillation is observed. If, however, as vapor is removed from a mixture, relatively more of a low-boiling component is removed, and the compositions of both vapor and residue change, the distillation temperature will not be constant. The actual changes in this case may depend on the type of vessel used for the distillation (see Fractional Distillation, p. 10).

The most common cases of constancy of distillation temperature are pure substances, and this fact may generally be used as a criterion of the purity of a substance; but there are many mixtures of such character that the composition of the vapor at the boiling point is the same as the composition of the liquid, so that as distillation proceeds no change results and the distillation temperature is constant. If the pressure remains constant, a pure substance distills at a constant temperature; but not every substance that distills at a constant temperature is a pure substance.

Distillation of a pure substance. On account of mechanical difficulties in distilling small quantities, care must be exercised in determining whether or not a substance does distill at a constant temperature. If the temperature changes are observed as heat is applied to a small quantity of liquid in a distilling flask, results as plotted in Fig. 4 may be obtained. An inexperienced observer sometimes reads temperature *A* as the starting point of the distillation; another may take temperature *C*. The real temperature is *D*, and the difference between *C* and *D* is due either to a lag in the thermometer or to a trace of low-boiling impurity. Lag in the thermometer may be avoided by using a very small flame and observing the condensing vapor as it ascends the neck of the flask. When it reaches the thermometer bulb, the heat is so regulated as to maintain an atmosphere of vapor about the bulb of the thermometer, without actually distilling the liquid, until the temperature is constant. If, after that, the temperature changes appreciably during the distillation, an impurity must be present. If, after the above precautions have been taken, it is observed that the temperature rises a few degrees after distillation begins, and then appears to remain constant, the receiver should be changed after the first few drops have reached the end of the condenser. Often a rise of one or two degrees during the whole distillation must be disregarded as representing superheating or as evidence of an impurity that cannot be separated on a small scale in such an apparatus. A rise in temperature at the end of the distillation represents superheating. It is never possible to drive all the liquid over.

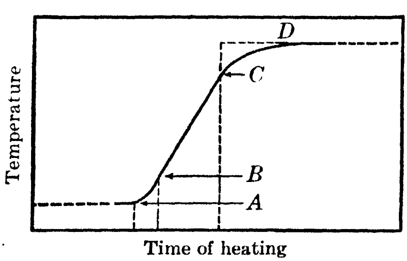
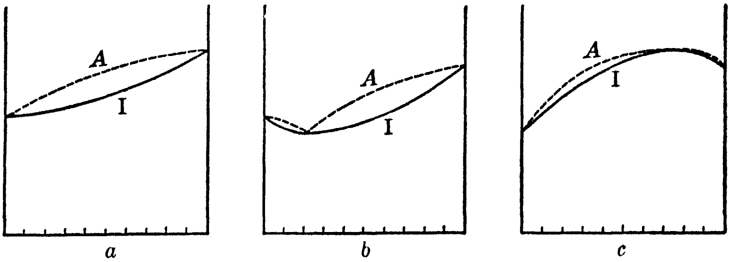


FIG. 4. The change in the thermometer reading at the beginning of the distillation of a pure substance

Fractional distillation of solutions. When a mixture or solution is distilled from a perfectly insulated flask, the composition of the first distillate is that of the vapor in equilibrium with the liquid at its boiling point, provided that no condensation of the vapor takes place in the neck of the distilling flask. In the case of most mixtures the vapor is richer than the liquid in the lower-boiling components and consequently the distillate is richer than the original in the lower-boiling components. The distillation temperature of such solutions *without condensation of vapor in the neck of the flask* is approximately the boiling point of the solution in the flask. The boiling point depends upon the composition of the solution; and since the composition changes as the distillation proceeds, the distillation temperature will be observed to rise gradually.

In curve I of Fig. 5, *a*, *b*, *c*, molal compositions of a series of binary solutions are plotted against their respective boiling points for three types of solutions. In those represented by

Fig. 5, *a*, the boiling point of any solution lies between the boiling points of the two pure constituents. For this type of solution the partial vapor pressures of the individual components and the total vapor pressure of the solution correspond more or less closely to Raoult's law (curves *A* and I, Fig. 2). Where wide deviations from this law occur, curves of the types shown in Fig. 5, *b* and *c*, are found. At some concentration in each of these cases the boiling point of the solution is either higher or lower than that of either pure component and is known as a maximum-boiling or minimum-boiling mixture of the components. The compositions represented by the maximum and minimum points of these curves cannot be compared strictly with those of curves III and II, respectively, of Fig. 2, since the latter curves are taken at constant temperatures. The composition of any constant-boiling mixture may vary with the distillation temperature and hence with the pressure under which the distillation is conducted. A maximum-boiling mixture, however, requires that at some composition and temperature the total vapor pressure of the solution be less than that of either pure component at the same temperature (curve III, Fig. 2), and correspondingly a minimum-boiling mixture requires that the total vapor pressure of the solution at some composition and temperature be greater than that of either pure component at the same temperature.



a *b* *c*

FIG. 5. Molal composition-boiling-point diagram for three types of binary solutions

When an equimolal mixture corresponding to Fig. 5, *a*, is distilled without condensation of vapor in the flask, the distillation temperature rises gradually to the boiling point of the higher-boiling component. If the distillate is collected in several portions as the distillation proceeds, differences in composition between them will exist. The first will be richer in the lower-boiling component, the last richer in the one of higher boiling point. If the first portion is redistilled under the same conditions, its distillation point will be found to be lower than the temperature at which it first distilled, and the first distillate from it will be still richer in the lower-boiling component. This process, called fractionation, can be continued until the first distillate is approximately the pure lower-boiling component.

The distillate at any moment under the conditions specified has the composition of the vapor in equilibrium with the boiling liquid. The composition of vapor (distillate) is represented by curve *A* on the same diagram with the composition-boiling-point curve (Fig. 5, *a*). A point on curve I represents boiling point and composition of the solution, and a point on curve *A* at the same temperature represents the composition of the vapor, or first distillate, in equilibrium with that solution. When this vapor is condensed and redistilled, it is seen to have a lower boiling point than that of the original solution, and to yield a distillate still richer in the lower-boiling component.

In an apparatus where condensation of vapor (refluxing) is possible the considerations just developed hold only for a small distance above the surface of the boiling liquid. Above this region the vapor is cooled and a portion condenses. In composition the condensate is slightly richer in the higher-boiling component, and correspondingly the vapor becomes slightly richer in the lower-boiling component. As this process continues, the point representing the composition of the vapor travels along curve *A*, Fig. 5, *a*, toward the lower-boiling component, and the condensate, or residue, approaches in composition more nearly that of the higher-boiling component. If a sufficient amount of condensation takes place in the neck of the flask or in a fractionating column, the first distillate will be the pure lower-boiling component. The purpose of a fractionating column (p. 17) is to insure a large amount of condensation with constant equilibrium established between vapor and condensate.

The results of an actual fractional distillation can be represented as in Fig. 6. The distillation temperature is plotted against the time of distillation, assuming no initial lag in the thermometer (cf. Fig. 4) and a constant rate of distillation. Curve I, Fig. 6, represents the case in which no condensation takes place in the neck of the flask. The temperature of distillation in this case is very nearly the boiling point of the liquid, and a gradual increase in the boiling point occurs as the composition of the liquid changes gradually. (Cf. curve I, Fig. 6.) Curve II represents the case in which there is perfect fractionation. The distillation temperature changes according to the composition of the distillate, remaining constant at first at the boiling point of the pure lower-boiling component, then rising rapidly as a distillate of variable composition comes over, then remaining constant again at the boiling point of the higher-boiling component. A thermometer placed in the boiling liquid residue during this operation would show only a gradual increase in temperature until the residue is the pure higher-boiling component. The amount of the intermediate variable distillate is determined by the type of fractionating column, and in no case can it be reduced to zero. Curve III represents an incomplete fractionation with some indication of the constant-boiling fractions, but not a sharp separation.

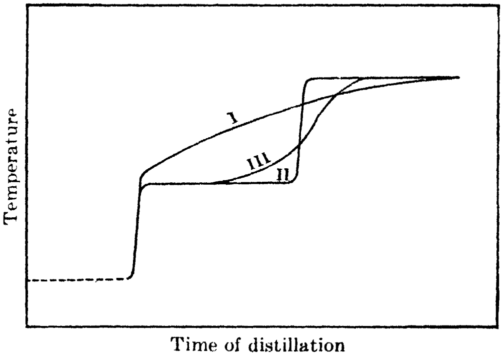


FIG. 6. The change in the thermometer reading during the distillation of a binary solution

With such widely different effects possible in the distillation of a mixture (depending on the type of apparatus, the rate of distillation, and the character of the components) it is impossible to give specific directions for carrying out a fractional distillation. The aim of the operation is to separate the material into portions each of which distills at a constant temperature. Some intermediate variable fractions cannot be avoided, and in many cases exact constancy cannot be expected. A distillation range of two, four, or occasionally even ten degrees may denote a relatively pure substance.

Given the vapor pressure of pure nitrobenzene as 49.6 mm. and that of ethyl alcohol as 3232 mm. at 120°, let us calculate the composition of a mixture of the two which boils at 120° under atmospheric pressure (760 mm.).

Assuming that nitrobenzene and alcohol form a perfect solution (that is, a solution which obeys Raoult's law), we have

$$p_A = p_{0A} N_A, \tag{1}$$

$$p_B = p_{0B} N_B, \tag{2}$$

where p_A and p_B are the partial vapor pressures of alcohol and nitrobenzene respectively over the liquid, p_{0A} and p_{0B} are the vapor pressures of the pure separate components at the same temperature, and N_A and N_B are the mol fractions of the two components in the solution.

$$N_A + N_B = 1. \tag{3}$$

$$p_A + p_B = 760. \tag{4}$$

Substituting (3) and (4) in (2) and using the given numerical value of p_{0B}, we obtain

$$760 - p_A = 49.6(1 - N_A). \tag{5}$$

Using in (5) the value of p_A obtained from (1), we have

$$760 - 3232\ N_A = 49.6(1 - N_A).$$

$$N_A = \frac{710.4}{3182.4} = 0.2232, \text{ or } 22.3 \text{ per cent.}$$

$$N_B = 1 - 0.2232 = 0.7768, \text{ or } 77.7 \text{ per cent.}$$

We may also calculate the composition of the vapor in equilibrium with the boiling liquid. The partial pressure of the alcohol vapor over the boiling solution is

$$p_A = p_{0A} N_A = 3232 \times 0.2232 = 721.4 \text{ mm.}$$

The partial pressure of the nitrobenzene is

$$p_B = p_{0B} N_B = 49.6 \times 0.7768 = 38.5 \text{ mm.}$$

In the vapor phase (above the solution) the mol fractions of the components are represented by the equations

$$N_A = \frac{p_A}{p_A + p_B} \quad \text{and} \quad N_B = \frac{p_B}{p_A + p_B}.$$

$$N_A = \frac{721.4}{760} = 0.95, \text{ or 95 per cent (approx.).}$$

$$N_B = \frac{38.5}{760} = 0.05, \text{ or 5 per cent (approx.).}$$

If there is no refluxing in the distilling flask, this represents the composition, in mol percentage, of the first part of the distillate from the solution. By weight the ratio of alcohol to nitrobenzene is as follows:

$$\frac{\text{Alcohol}}{\text{Nitrobenzene}} = \frac{95 \times 46}{5 \times 123} = \frac{4370}{615}.$$

The percentage of nitrobenzene, by weight, in the first distillate is

$$\frac{615}{4985} \times 100, \text{ or 12.3 per cent.}$$

In the original solution the percentage of nitrobenzene, by weight, is

$$\frac{77.7 \times 123}{(77.7 \times 123) + (22.3 \times 46)} \times 100, \text{ or 90.3 per cent.}$$

Steam and vacuum distillation.* Many substances decompose when heated to the temperatures of their boiling points. Others which would ordinarily stand the boiling temperatures may be obtained in such mixtures that direct fractionation is impractical, owing to bumping, the presence of solids, or the possibility of reaction with the impurities. Under these circumstances advantage is taken of the fact that even at a temperature lower than the boiling point every substance is more or less volatile, and that if the vapor can be carried out and condensed, a distillation at a lower temperature may be effected. A distillation in vacuo is such a process, where the external pressure is made lower than that of the vapor at a given temperature, and distillation proceeds.

Steam distillation is carried out at ordinary pressures, in vacuo, or at increased pressures. Steam is passed through the solution and serves to carry out with it the vapor of the substance. On condensing, the substance may be separated from the water mechanically, or it may be extracted with a suitable solvent. Air or any other gas could be used equally well, except that the steam serves to heat the substance, the temperature is readily controlled, and all the distillate condenses to liquids or solids. It is not necessary to generate the steam in a separate vessel if the aqueous mixture can be boiled without bumping.

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* See the section on Distillation Apparatus for description of the apparatus used in vacuum and steam distillations.

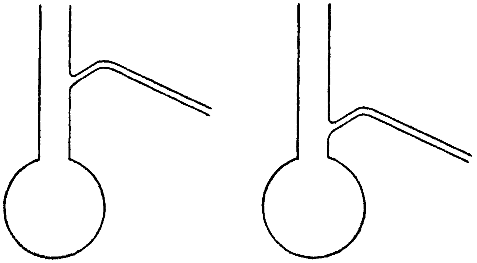
FIG. 7. Distilling flasks

Distillation apparatus. The best distilling apparatus is designed to offer good fractionation and to prevent the mechanical transport of spray, by the vapor, into the condenser. A flask should be used of such a size that it is about two-thirds full at the beginning of the distillation, and the bulb of the thermometer should be opposite the side neck.

To stop spray it is well to have the side neck project upward for a distance of about two inches as it issues from the flask, and then downward to accommodate the condenser. For a high-boiling liquid the side neck should be placed low in the neck of the flask; for a low-boiling liquid a fractionating column or a flask with a high side neck should be used. Specially designed forms of distilling flasks and fractionating columns are in use. A few designs are represented in Figs. 7 to 16.

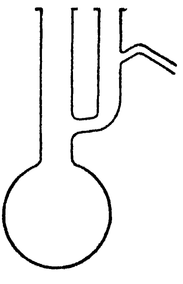
FIG. 8. Claisen flask

The Claisen type of flask is particularly useful to stop spray and foam in case of violent bumping on boiling. For the distillation of solids the apparatus shown in Fig. 9 may be used. The unjacketed condenser permits the application of heat to prevent the clogging of the condenser by the solidified distillate. The bent tube connecting the distilling flask and condenser must be large enough to permit the passage of liquid and vapor. It should be at least 5 mm. in internal diameter. In place of the bent tube, if a thermometer is desired, the short column shown may be used. Wherever possible it is better to use an ordinary distilling flask for high-boiling substances, because, in the apparatus as shown, the hot vapor comes in contact with a cork stopper, leading to possible contamination, and because of the excessive amount of refluxing caused by the relatively high outlet.

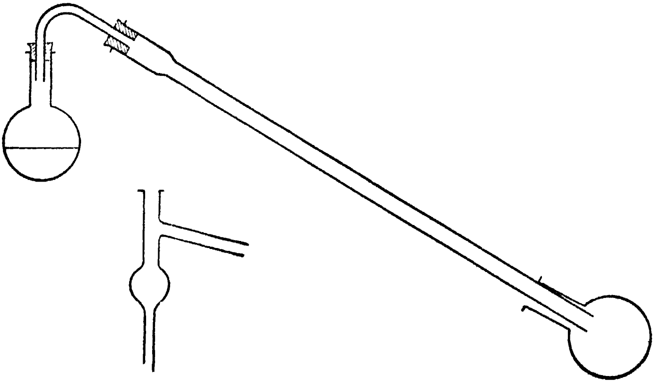

FIG. 9. Air condenser and two types of connecting tubes

A fractionating column causes some condensation (refluxing) and brings about such contact between the ascending vapor and the descending condensate as to insure constant equilibrium between the two phases. The design of the column shown in Fig. 10 has the advantage of simple construction and large contact surface as compared with volume. If the indentations slope definitely downward, the refluxing liquid is caused to drop down the center of the column instead of running down the sides, thus making better contact between the liquid and vapor.

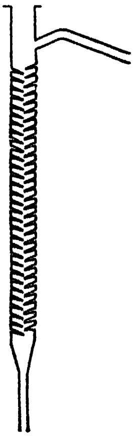

FIG. 10. Fractionating column

A trap (Fig. 11) is designed to avoid refluxing and to prevent the passage of spray or solid particles. It is necessary for this purpose to cause a change in the direction of flow of the stream of vapor.

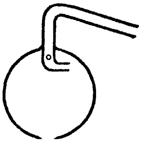

FIG. 11. Spray trap

A vacuum distillation apparatus is shown in Fig. 13. All stoppers are of rubber. It is necessary to use thick-walled rubber tubing that will not collapse when the pressure within the system is reduced. The pressure, as shown on a manometer, is brought to the desired point by means of a vacuum pump while a steady stream of dry air is flowing from the capillary opening of the glass tube that dips beneath the surface of the liquid. Heat is then applied carefully and the distillation is carried out as usual. If only one fraction is desired, it is convenient to use a distilling flask for the receiver in the first operation. The receiver may then be used as a distilling flask in a second run. If more than one fraction is desired, two types of receiver are in common use, represented in Figs. 13 and 14. In Fig. 13 a turn of the handle brings an empty receiver under the outlet. In Fig. 14 the

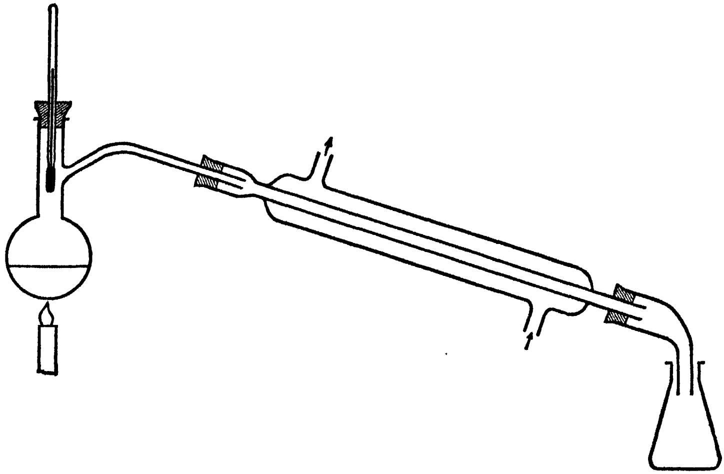

FIG. 12. Water-jacketed condenser and adapter

condenser is connected to the upper left opening, the vacuum line to the upper right opening, and a round-bottomed flask to the vertical opening. The lower right opening is an inlet for air. By proper manipulation of the stopcocks the round-bottomed flask may be filled and replaced at will without stopping the distillation. Goggles should be worn during the evacuation and distillation, and only round-bottomed flasks should be used. Excessive bumping occurs when a distillation is conducted at very low pressures. A pressure of from 10 mm. to 100 mm. will generally be found satisfactory and safe.

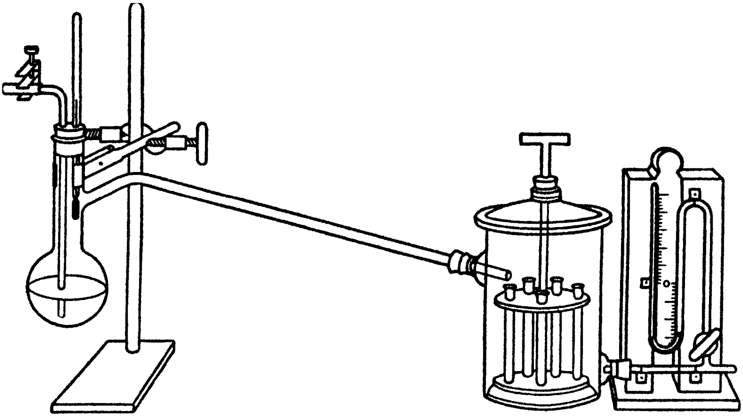

FIG. 13. Vacuum distillation apparatus

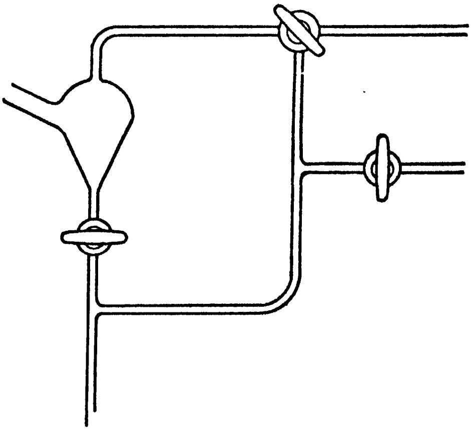

FIG. 14. Receiver for use in vacuum distillation

An apparatus for steam distillation is shown in Fig. 15. The accumulation of condensed steam in the second flask should be avoided by using superheated steam, by heat insulation, or by the application of heat. A rapid flow of steam does not necessarily cause a greater rate of distillation of the product desired, but does so to the extent that the jet of steam atomizes the liquid phases and hastens volatilization. The flask is tilted to avoid, as far as possible, the passage of spray into the condenser.

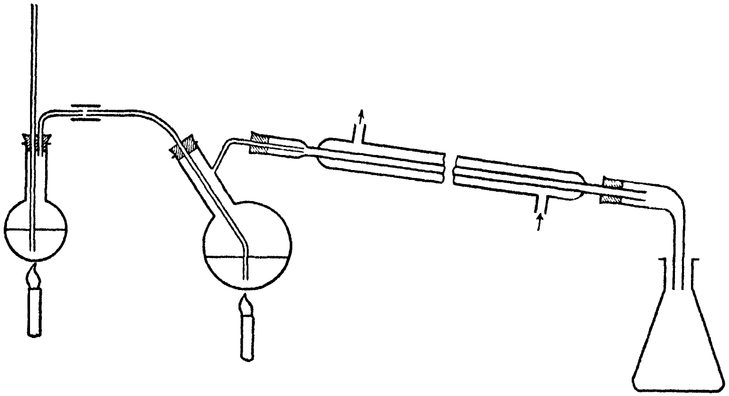

FIG. 15. Steam distillation apparatus

Types of reflux condensers are shown in Fig. 16. The diameter of the upright tube must be large enough to permit the passage of vapor and liquid. This will depend upon the surface tension of the liquid that is being condensed and upon the amount of the condensate. Liquid and vapor will pass each other more readily in a sloping than in a vertical tube. The tube must be long enough, as related to the rate of heating and the heat of vaporization of the liquid, to remain cold at the top. For substances boiling below 100° a water-jacketed reflux condenser should be used. If the top of the condenser is to be protected from atmospheric moisture by a calcium chloride tube, a connecting adapter should be arranged so that any condensation in the calcium chloride tube will not reflux to the flask. There is no advantage to be gained by boiling a solution rapidly under a reflux condenser. Heterogeneous mixtures may be kept stirred by boiling, and in some cases this may warrant vigorous boiling and the use of a very efficient condenser.

Distillation of inflammable liquids. When a volatile and inflammable liquid is distilled, there is danger that the vapor from the receiver may be ignited by a lighted burner. To reduce the danger use a distilling flask for the receiver and pass the condenser tube through a cork into the neck of the flask. Fasten a rubber tube to the side arm of the receiving flask and convey the escaping vapor to the sink or to the floor.* As a further precaution the receiver may be cooled in ice. Except where flames are very near the receiver these precautions are unnecessary in the distillation of liquids that boil above 70°.

Absorption of poisonous gases. In many reactions poisonous or obnoxious gases are evolved. Experiments involving such reactions should be conducted under a hood having a good draft. If this is not possible, the gases should be conveyed by delivery tubes to suitable exits from the laboratory, or they should be absorbed. In the latter case, if the absorbing substance is a liquid, the apparatus should be so designed that the liquid cannot be drawn back into the reaction vessel (see Fig. 30). There is danger of this if the gas is absorbed rapidly. Several methods for absorbing gases are in common use. If the gas is very soluble in water, it can be discharged through a water suction pump. The gas is carried from the receiving flask (in the case of distillation) or from the

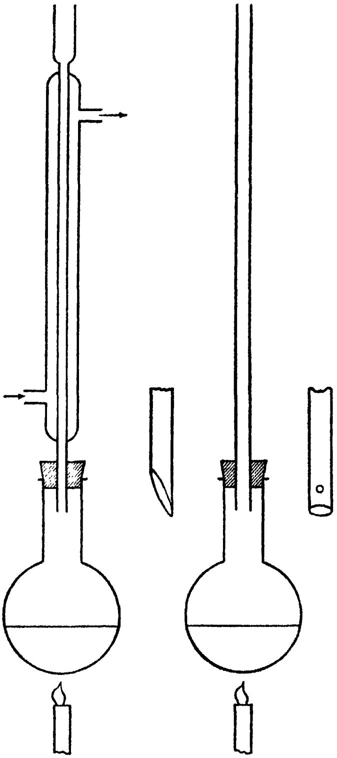

FIG. 16. Reflux condensers

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* Be sure that the side arm of the receiver and the tube leading from it are open. Do not try to distill in a closed system.

top of a reflux condenser (in the case of digestion) through a T tube. One arm of the T is connected with the water pump, and one arm is left open to maintain atmospheric pressure in the system. The pump is kept in operation during the experiment. The gas is drawn into the pump and is discharged in the stream of water into the sink.

In another device the gas escapes through an inverted funnel, which dips below the surface of the absorbing liquid contained in a beaker. The depth to which it dips and the size of the funnel and of the beaker should be so adjusted that if the liquid is drawn back into the funnel the level of the liquid in the beaker will fall below the rim of the funnel before the latter is full.

In many cases an objectionable gas may be removed from the other gaseous products of a reaction by passing the mixed gases through an absorbent which acts selectively upon the components. An example of this type of operation is outlined in the removal of sulphur dioxide and ether from ethylene (see Fig. 30, p. 60). A safety device, as used in the ethylene experiment, obviates the danger of having the absorbent drawn back into the generating flask. Whenever the gas forms a sparingly soluble solid with the absorbing liquid, it should be led into the latter by a tube of large diameter, so as to prevent the solid from clogging the tube.

A solid absorbent such as calcium chloride or soda lime in granular form may be used. Solid absorbents have the advantage of permitting gas to flow in either direction, but they are subject to clogging and channeling. The reagent is usually placed in a vertical tube so as partly to overcome the tendency to form channels; hence the term *absorption tower*.

The following table gives absorbents for gases commonly generated in organic syntheses:

Halogen acids	Water
Halogens Acid halides Hydrogen cyanide Hydrogen sulphide	Sodium hydroxide solution or soda lime
Ammonia Amines	Dilute sulphuric acid

EXTRACTION

The components of a mixture may be separated by treatment with a solvent in which they have very different solubilities. For instance, a mixture of sodium chloride and barium sulphate can be separated by treatment with water in which sodium chloride dissolves. A mixture of salt and acetoxime cannot be separated by extraction with water, but the separation may be effected by using alcohol in which only the acetoxime dissolves. If these compounds were present in an aqueous solution, the separation could be made by extraction with ether, since acetoxime is soluble in ether and the two solvents are not miscible with each other.

Extraction from solution is accomplished by shaking the solution with the extracting solvent in a separatory funnel (Fig. 17). It is advisable to use a funnel of such size that it is filled to about three quarters of its capacity. If a very volatile solvent is employed, the stopper should be removed occasionally (or the funnel inverted and the stopcock opened) in order to relieve pressure. Vigorous shaking is advisable unless such treatment produces an emulsion that prevents separation into two layers. In such cases gentle agitation for a longer time is better. The addition of a few drops of alcohol often prevents the formation of an ether emulsion. The lower layer should be run out through the stopcock, and the remaining solution should then be poured out from the top of the funnel. This prevents contamination with the liquid adhering to the stem of the funnel. After the separation has been made, the nonaqueous layer is dried (see page 45) and the solvent is removed by distillation.

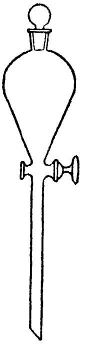

FIG. 17. Separatory funnel

When a solution of a substance in any solvent is shaken with a second solvent which is immiscible with the first, the solute distributes itself between the two solvents in such a way as to establish an equilibrium between the solute remaining in the first solvent and that acquired by the second. A definite ratio then exists between the concentrations of the solute in the two phases.

The equilibrium established may be represented by the equation

$$\frac{c_1}{c_2} = k,$$

where c_1 is the concentration (grams per cubic centimeter) in one solvent, c_2 is the concentration in the second solvent, and k is a constant. An approximate value of k can be found by determining the solubility of the solute in each of the solvents independently; for if each separate solution is in equilibrium with the pure solute, the two solutions, when brought together, should be in equilibrium with each other. The constant k is known as the partition coefficient of the solute with respect to the two solvents.* The distribution of the solute between the two solvents, however, is exactly proportional to its solubilities in the separate pure solvents only within the range of concentration where the solutions obey Raoult's law (see page 5) and only if the two solvents are completely immiscible.

Suppose a substance is three times as soluble in ether as in water, and we have 10 g. of the substance in 100 cc. of water. If we shake this solution with 50 cc. of ether, the solute will distribute itself between the two solvents in such a way as to make the concentration of the solute in the ether layer three times as great as in the aqueous layer. Let x be the amount taken up by the ether; then $10 - x$ is the amount remaining in the water, $\frac{x}{50}$ is the concentration in the ether, and $\frac{10 - x}{100}$ is the concentration in the water. Then

$$\frac{\frac{x}{50}}{\frac{10 - x}{100}} = \frac{3}{1}, \quad \text{or} \quad x = 6 \text{ (grams)};$$

that is to say, $\frac{6}{10}$, or 60 per cent, of the substance has gone into the ether layer.

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* Numerical values of partition coefficients for the common solvents are given in many tables of physical constants. See Landolt and Börnstein, Physikalisch-Chemische Tabellen, 5th Ed., Vol. I, p. 743. Springer, Berlin, 1923.

We may express this in a general way for any pair of immiscible solvents. Suppose a solution containing b grams of solute in v_1 cubic centimeters of solvent A is shaken with v_2 cubic centimeters of solvent B. If x is the amount of the substance taken up by solvent A, the concentration in this layer will be $\frac{x}{v_1}$; in solvent B the concentration will be $\frac{b-x}{v_2}$; and

$$\frac{\frac{x}{v_1}}{\frac{b-x}{v_2}} = \frac{c_1}{c_2} = k.$$

With a given quantity of solvent a more complete separation can be made by using it in small portions for successive extractions than by using the entire quantity in one operation. In the example given above, 100 cc. of an aqueous solution containing 10 g. of a solute yielded 6 g. of the substance to 50 cc. of ether in one extraction. Suppose two successive extractions had been made with 25-cubic-centimeter portions of ether. The amount x removed in the first process is given by the equation

$$\frac{\frac{x}{25}}{\frac{10-x}{100}} = \frac{3}{1}, \quad \text{or} \quad x = 4.3 \text{ (grams)}.$$

The amount remaining in aqueous solution is 5.7 g. In the second extraction

$$\frac{\frac{x}{25}}{\frac{5.7-x}{100}} = \frac{3}{1}, \quad \text{or} \quad x = 2.4 \text{ (grams)}.$$

In the combined ether extracts (50 cc.) we have 6.7 g. instead of 6 g. of the solute. The question as to whether one should repeat the operation several times, using small quantities of solvent, or take enough of the solvent to obtain substantially all of the solute in one extraction is settled by consideration of the partition coefficient, the cost of the solvent, and the time required to complete the work.

The solubility of almost any organic compound is less in a salt solution than in pure water. Even if the dissolved substance does not appear as a separate layer, or as a precipitate when salt is added, its solubility may be reduced to such an extent that an ether extraction is much more complete than it would be in the absence of the salt.

In separating a soluble substance from the insoluble components of a solid mixture a Soxhlet apparatus is generally employed (Fig. 18). The solvent is placed in a small flask *A*, which is heated on a water bath or on an electric hot plate. The material to be analyzed is reduced to small particles by grinding and placed in a porous tube (a paper extraction thimble) *B*. The tube containing the sample is inserted in the extraction tube *C*, which is attached by a ground-glass connection to the flask *A* and by a similar connection to a condenser *D*. When the flask is heated, the vapor of the solvent passes through the side tube *E* to the condenser. It drips back onto the sample in *B*, diffuses through the walls of the tube freely, and maintains the same level in the thimble and in the glass chamber *C*. When the siphon *F* is filled, it starts a rapid discharge of the solvent, with its first load of extracted matter, into the flask *A*. The cycle is then repeated. The process continues automatically as long as heat is applied to the flask. A fresh supply of the pure solvent is provided in each cycle when the Soxhlet apparatus is used. This increases the rate of extraction, — a matter of considerable importance in the removal of a soluble component from solid material. Finally flask *A* is removed and the solvent is distilled off, leaving as a residue the extracted matter.

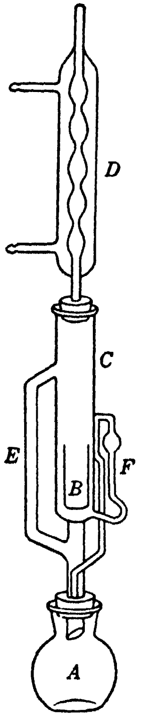

FIG. 18. Soxhlet extractor

Differences in rates of solution of the soluble components of a mixture may be made the basis of a more or less complete separation. The black ash produced in the Leblanc process for making soda contains sodium carbonate and calcium sulphide. Sodium carbonate dissolves much more rapidly than does calcium sulphide, and this difference in rate of solution makes a separation possible. It is a result that would not be predicted from a consideration of the total solubilities of the components without reference to rates of solution. Similarly, hot water extracts caffeine and the desirable flavors from coffee more rapidly than it dissolves the tannins and other bitter components. To avoid an appreciable extraction of the latter, coffee should not be subjected to the action of boiling water for a long time (ten minutes is a practical limit); but in order to secure the desired "strength" in the beverage in an extraction of short duration, it is necessary to use a relatively large quantity of the ground material.

FILTRATION

The process of filtration is used to separate solid from liquid substances, as in the separation of crystals from their mother liquor in crystallization, or the removal of any insoluble material from a liquid. The actual method to be employed is determined by a great variety of conditions.

Apparatus. An ordinary funnel and filter paper suffice for most filtrations, but special forms of apparatus are almost indispensable under some circumstances. The chief disadvantages of the ordinary funnel are the slowness of the process, limitation to room temperature, and the difficulty of completely removing the mother liquor from a fine precipitate or from one which is fairly soluble in the solvent.

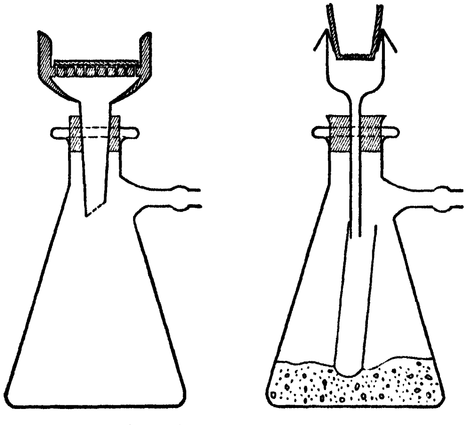

FIG. 19. Suction filter flasks fitted with Büchner and Gooch funnels

To overcome these difficulties filtration by suction is used. The ordinary side-arm suction flask (Fig. 19) is fitted by means of a rubber stopper to a perforated porcelain (Büchner or Gooch) funnel. An ordinary funnel equipped with either a perforated platinum cone or a rubber ring in which is set a porous porcelain cone may be used. If a platinum cone is used, filter paper is fitted to the funnel so that no air may pass around the edge of the paper when suction is applied. In a porcelain funnel with a flat bottom the paper should lie flat and not extend up the sides. Before the liquid to be filtered is added, the paper should be wet with the solvent and drawn down by suction. When a very fine precipitate is present, it is well to allow the funnel to stand for five minutes after filling with the liquid containing the suspended particles before suction is applied. This allows the heavier particles to settle and cover the paper. If the suction were applied immediately, the fine particles would be forced into the paper and would clog the filter. If the filtration is being performed in order to isolate crystals or a precipitate, provision should be made for the complete removal of the mother liquor by washing (see page 33).

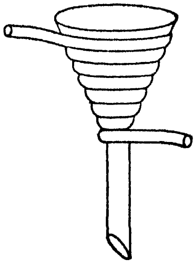
FIG. 20

If the liquid phase is the one desired, the filtration should be performed while the liquid is hot, since it then filters much more rapidly. Rapid suction filtration usually permits the clarification of a hot concentrated solution without the deposition of crystals on the filter, particularly if the funnel has been previously heated by pouring some of the hot solvent through it. If the solution cannot be filtered hot in this way without the separation of crystals, the funnel must be kept hot during the operation. A useful device for this purpose consists of a small lead tube wound around the funnel as indicated in Fig. 20. Steam is passed through the

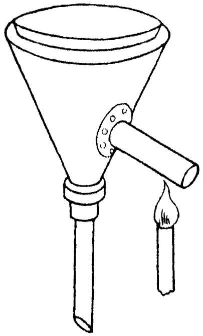
FIG. 21

tube while the process of filtration is in progress. Steam-jacketed funnels, as shown in Fig. 21, are available, and they are more efficient than funnels heated by coils of lead tubing.

CRYSTALLIZATION

Fractional crystallization constitutes a useful means of separating the components of many mixtures. The method is commonly employed to purify a compound; that is, to separate it from small quantities of foreign bodies. In such cases it is not necessary to recover the contaminating substances, and the procedure is simpler than when each component of the mixture must be obtained in a pure state.

Six steps are essential in the crystallization process: (1) solution of the solid, (2) clarification of the solution, (3) crystallization, (4) removal of the crystals from the mother liquor, (5) washing of the crystals, and (6) drying of the crystals. Only as a last resort should *all* of the solvent be allowed to evaporate to effect crystallization.

Solution of a solid; choice of solvent. Some common solvents are water, methyl alcohol, ethyl alcohol, benzene, gasoline, acetone, acetic acid, toluene, ethyl acetate, chloroform, nitrobenzene, and carbon tetrachloride. A solvent should be found in which the compound dissolves readily when heated and from which it precipitates on cooling. If the substance dissolves at room temperature in a small volume of the solvent, or if it fails to dissolve appreciably when heated, the solvent is not a satisfactory medium for the crystallization. The rate of solution is often slow, even at elevated temperatures, however, and a solvent should not be discarded as useless on the basis of failure to dissolve the substance immediately. On the other hand, slow crystallization from solution is a common phenomenon, and one should not decide too hastily that the solute does not precipitate when the saturated solution is cooled. Very often failure to crystallize on cooling is due to the fact that the hot solvent was not actually saturated with the solute. A solid residue remaining for a few minutes in contact with the boiling solution does not necessarily mean that the solid is in equilibrium with the liquid phase. It may mean that the solid is dissolving so slowly that there is no visible evidence of its disappearance.

It is sometimes necessary to inoculate a supersaturated solution with a crystal of the solute to start the crystallization. If the substance is very soluble in the solvent chosen, it may fail to crystallize on cooling, even when inoculated with the solid phase and allowed to stand for several hours. Under such circumstances crystallization may be induced by evaporating off part of the solvent. As a rule a solvent in which the substance is very soluble should not be used.

It is often possible to prepare a suitable solvent by mixing two liquids which are soluble in each other but which differ in their capacities to dissolve the compound to be crystallized. Thus mesitol is soluble in alcohol and insoluble in water, but alcohol and water are miscible with each other. By dissolving mesitol in hot alcohol and adding just enough hot water to produce a slight turbidity a solution is obtained from which mesitol crystallizes on cooling. Benzene and gasoline, acetone and water, ligroin and ether, and alcohol and ether are other pairs of solvents that may be used in this way.

As a rule the substance should be dissolved in the smallest possible quantity of hot solvent. However, enough solvent should be used to permit cooling the solution to a temperature below the melting point of the solute before the saturation point is reached. It is not always good practice to use enough solvent to dissolve the sample completely. A very small residue may be a slowly dissolving portion of the desired substance or it may be a small amount of a very insoluble impurity. It is better practice to isolate the residue by decantation or filtration and test its solubility in a fresh portion of the solvent.

The least soluble component of the mixture may be the one to remain in solution after the main product has crystallized from the mother liquid. This is the case when the relatively insoluble substance is present in very small amount. The solvent, on cooling or evaporating, then becomes saturated with the main product, which is present in large quantities, before the concentration of the contaminating substance reaches its saturation value. The solubility curves (Fig. 22) make this point clear, and they indicate also the advantage that may be gained, in some instances, by fractionally crystallizing the mixture at two different temperatures. Crystallizing at two different temperatures, or from two different solvents, is generally necessary if both components of a mixture must be recovered as pure products.

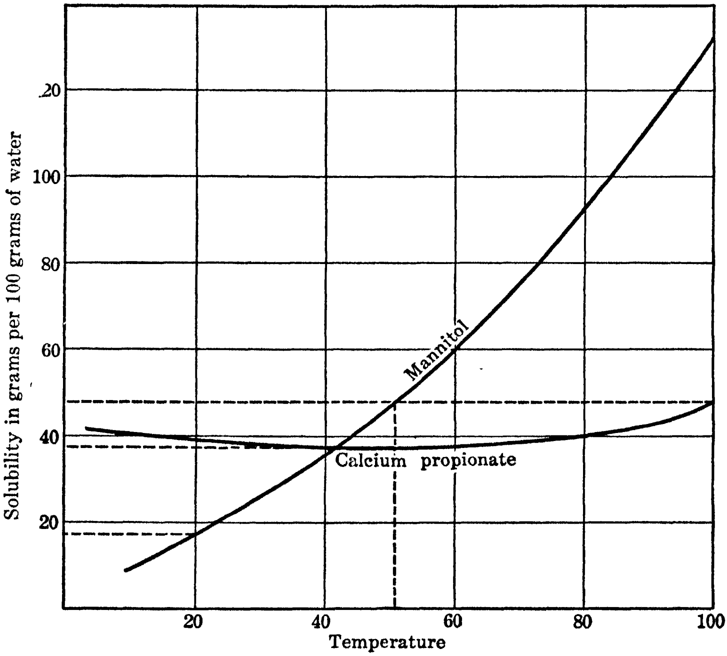

FIG. 22. Solubility in water of mannitol and calcium propionate between 10° and 100°

Suppose we have a mixture containing equal quantities of mannitol and calcium propionate. If the mixture is dissolved in the smallest possible volume of water at 100°, it is obvious from the curves that the solution is saturated with respect to calcium propionate but is far from the saturation point with respect to mannitol. It contains 48 g. of each component in every 100 g. of solvent. It can be cooled to 51° without depositing mannitol, but on cooling to this temperature 10 g. of calcium propionate will crystallize. Further cooling does not appreciably change the solubility of the calcium salt but does cause the crystallization of mannitol. On cooling from 51° to 20°, approximately 30 g. of mannitol will be precipitated. This crop of crystals will be almost free from calcium propionate, for although a small amount of the salt is precipitated between 51° and 45°, it redissolves (slowly) at the lower temperature. It must be remembered, however, that these calculations are based upon the assumption that the solubility of one component is not changed by varying the concentration of the other component, — an assumption that is often far from true.

When the task is that of purifying a product by the removal of a small quantity of some foreign substance, we are interested in the recovery of one product only. Suppose, for example, that a sample of mannitol is contaminated with 1 per cent of its weight of succinic acid. We may dissolve the sample in water at 85° to obtain a solution containing 100 g. of mannitol and 1 g. of succinic acid in 100 g. of water. On cooling to 0° the solvent will retain less than 10 g. of mannitol (90 g. of mannitol will crystallize out), but the solvent will still be far from saturated with respect to succinic acid.

A solvent should be chosen with which the substance to be crystallized does not react; in which it is more soluble hot than cold; in which it is neither sparingly soluble nor very soluble; in which the impurities are either totally insoluble or very soluble or have temperature coefficients of solubility radically different from that of the substance desired. When no one solvent meets these requirements, a mixture may be used, such as alcohol-water, alcohol-ether, benzene-ligroin, etc.

Clarification of the solution. Crystals should never be allowed to deposit from a solution that is not optically clear. If it is not clear, or if there is an insoluble residue present, the solution should be filtered before permitting crystallization to take place.* Some suspensions and soluble colored impurities cannot be removed by filtration, and they become adsorbed, or occluded, in the crystals. Such substances may often be removed by heating the solution with about one third its volume of animal charcoal until the desired clarification has been achieved, and then filtering the hot solution to remove the charcoal.

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* See page 28 for methods of filtering hot concentrated solutions.

Crystallization. Rapid crystallization, resulting in fine crystals, gives a purer product than a slow crystallization yielding large crystals, owing to the occlusion of impurities in the large crystals. It is best carried out in a beaker of such size as to give depth to the solution. Slow evaporation of a solution results in the formation of crystals at the surface. Such a process approximates the complete removal of the solvent and results in the deposition of impurities with the crystals. Moreover, many types of impurities are highly adsorbed in the surface film and hence have a higher concentration at the surface than in the body of the solution. Therefore crystallization should not be allowed to take place by spontaneous evaporation if it can be avoided. Where evaporation of the solvent is necessary it should be boiled off, either at ordinary pressure or in vacuo, but never completely, and in any event the crystals should not be allowed to become wholly dry, but should be kept immersed in the liquid. If the interior of the container is not rubbed with a glass rod during crystallization, the crystals will not adhere to the sides. If supersaturation is suspected, scratch the container with a glass rod and place in the solution a small crystal (seed). Plan to let the solution stand at least one hour after cooling, to crystallize; preferably allow it to stand overnight.

Removal of crystals from mother liquor. To remove the crystals use any of the methods of suction filtration described on page 27.

Washing of crystals. The mother liquor adhering to the crystals should always be removed. If possible remove the crystals from the filter, moisten them thoroughly with fresh solvent, and replace them on the filter. If that is not possible, disconnect the pump* and mix the crystals carefully with a small quantity of fresh solvent on the filter. The *last* washing may be made with larger quantities of a liquid in which the solvent used is soluble but in which the crystals are insoluble. Press out the crystals on a porous plate or between filter-paper pads.

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* If the water is shut off when a water suction pump is attached to an evacuated vessel, water will be forced into the apparatus.

Drying of crystals. The solvent or wash liquid should be entirely removed by air drying in a place free from dust or in a desiccator (see Methods of Drying). In no case leave the crystals on filter paper to dry. Spread them out in a flat crystallizing dish and when dry place them in a covered container.

SUBLIMATION

A solid which has a relatively high vapor pressure at a temperature below its melting point will sublime. When heated it will volatilize and the vapor on cooling will condense to the solid state without the appearance of the liquid phase. Certain solids which undergo this change are purified by sublimation instead of distillation. A convenient form of apparatus consists of two beakers, one inside the other, the inner one being filled with water to present a cold surface for the condensation. If a sublimation is to be carried out in vacuo, a retort is used (Fig. 23). The wide outlet tube is connected with the vacuum pump and serves as a condenser and a receiver for the sublimate.

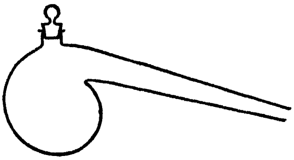

FIG. 23

The chief difficulty in a sublimation process is that the condensed vapor is a solid rather than a liquid and is often in the form of a very fine dust which will not settle rapidly. The operation, therefore, to be effective, must be carried out slowly.

A convenient form of apparatus, suitable for the purification of many volatile solids, consists of an evaporating dish covered with a sheet of perforated paper and an inverted funnel (Fig. 24). The material is heated in the evaporating dish. The vapor passes through the pinholes in the paper and crystallizes in the funnel. The paper catches any crystals that drop from the funnel. The condenser may be cooled by a stream of water flowing through a coil of lead tubing wrapped around the funnel (Fig. 20).

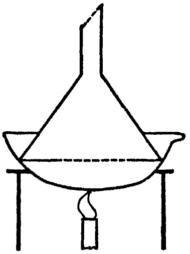

FIG. 24

DETERMINATION OF THE BOILING POINT

The boiling point is that temperature at which the vapor pressure of the liquid is equal to the external pressure. The normal, or corrected, boiling point is the boiling point at 760 mm. of mercury pressure.

The boiling point can be taken in the course of a distillation as the constant temperature observed during the process. The distillation method requires a relatively large amount of material, and if the boiling point of a mixture were desired, this method might not be suitable at all.

A fairly accurate determination of the boiling point can be made with a few cubic centimeters of liquid by using a side-neck test tube as a distilling flask and a very small flame. Distillation is not essential. The thermometer must be immersed in the pure vapor at a known pressure, and if a deep test tube with a high outlet is used, the ring of condensing vapor will mark the position below which the bulb of the thermometer must be when the reading is made.

Another method makes possible the determination of the boiling point by using only 0.5 cc. of liquid. A thin-walled tube of about 3 mm. internal diameter and 10 cm. long is sealed at one end. A melting-point tube 0.5 mm. in diameter and somewhat longer than 10 cm. is constricted 3 mm. from one end so as to form a short closed tube. A bend is then made at the other end so that the smaller tube will hang in the larger one without touching the bottom. Enough liquid is placed in the larger tube to cover the constriction in the capillary tube. The tubes are then placed in a bath and the temperature is raised until a stream of bubbles flows from the end of the immersed capillary tube. The bath is then allowed to cool until the bubbles cease forming and the liquid is seen to rise in the tube. The liquid is at its boiling point when bubbles cease to form and this condensation occurs. The method depends upon the replacement of the air in the capillary tube by the vapor. When the liquid rises in the tube, the pressure of the vapor is atmospheric plus a correction for surface tension effects (capillary attraction) and a correction for the hydrostatic pressure of the liquid.

Corrected boiling points. The determination of the boiling point is usually made at the prevailing atmospheric pressure. The normal, or corrected, boiling point involves a correction to reduce the observed boiling point T_B to the boiling point at 760 mm., which we will designate as T_{B_0}. The rule of Crafts states that the correction Δt, to be *added* to the boiling point T_B on the absolute scale, determined at a pressure P millimeters, is given by the equation

$$\Delta t = KT_{B_0}(760 - P),$$

where K is a constant.

This equation gives only an approximately accurate value. The constant K varies somewhat with P, and the equation is therefore useful only when $(760 - P)$ is small. If $(760 - P)$ is small, then the observed boiling point T_B at pressure P can be substituted for T_{B_0} in the equation.

The value of K varies with different liquids. For nonassociated liquids it is about 0.00012. Values of K for a few liquids are given below.

SUBSTANCE	$K \times 10^4$
Acetone	1.19
n-Octane	1.20
Benzene	1.22
p-Xylene	1.36
Ethyl ether	1.29
Acetic acid	1.0
Water	1.01
Stannic chloride	1.35
n-Butyl alcohol	0.90
Methyl alcohol	1.0

EXAMPLE. Calculate the normal boiling point of methyl alcohol if it boils at 65° C. at 707 mm.

$$\Delta t = 1.0 \times 10^{-4} \times (65 + 273) \times (760 - 707) = 1.8^\circ \text{ C.}$$
$$T_{B_0} = 66.8^\circ \text{ C.}$$

What difference would it make in the corrected boiling point if the value 1.1×10^{-4} had been assumed for the constant K?

For the effect of impurities on the boiling point consult the section on Distillation (p. 6).

DETERMINATION OF THE MELTING POINT

The melting point of a substance is that temperature at which the solid and molten phases of the material when in contact with each other are in equilibrium. When in equilibrium the solid will not melt nor the liquid freeze without the addition or subtraction of heat; or, if heat is added or subtracted, the temperature will not change until one or the other phase disappears. The problem is to determine this temperature with a definite degree of accuracy.

As a rule the equilibrium between the two phases is approached rapidly from one side only; that is, in the conversion of the solid to the liquid.

$$\text{Solid} \rightleftarrows \text{liquid.}$$

The reverse reaction, liquid to solid, is often very slow and results in a "supercooled" liquid. Crystalline solids are not superheated, and when the solid melts, one may be reasonably sure that the temperature at which this occurs is the actual melting point and not a higher temperature. This fact admits of a very simple method for the determination of the melting point.

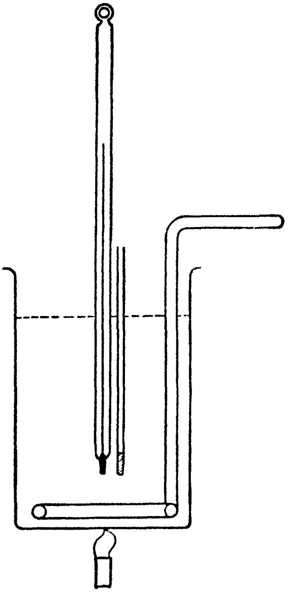

FIG. 25

Procedure for determining the melting point. Fig. 25 shows the apparatus to be used. A beaker containing concentrated sulphuric acid or other suitable liquid* is used as a bath for the immersion of a thermometer and of a sample of the material whose melting point is desired. The temperature is raised until the substance melts. With proper precaution the temperature at which this occurs can be determined within 0.5°. The sample is powdered and placed in a thin-walled capillary tube, which is held to the moistened thermometer by a film of the liquid. The capillary tube is best drawn from a heavy-walled test tube, and the size used should be as small as can be conveniently filled. The problem, then, is to regulate the apparatus so that the temperature as read on the thermometer records the actual temperature of the crystals at all times within the desired accuracy. This is made possible by control of the following factors:

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* Water may be used for substances melting below 100°. Glycerol, if anhydrous, can be used to a temperature of 290°. Ordinary concentrated sulphuric acid can be used to 280°, and if anhydrous sodium sulphate is added to concentrated sulphuric acid the bath is good to a temperature of 350°. Fused salts, such as zinc chloride and mixtures of sodium and potassium nitrate, may be used.

1. *Stirring of the bath.* In order to keep the temperature of the bath uniform throughout, the stirring should be more vigorous than the stirring caused by heat-convection currents alone.

2. *Position of thermometer and sample.* The sample contained in a thin-walled, narrow tube should be close to the bulb of the thermometer. The depth of immersion of the instrument in the bath is determined by the method used in its calibration (see page 40). In general, the bulb of a total-immersion thermometer should be at least an inch below the surface and approximately the same distance from the bottom of the bath. The proper depth for a partial-immersion thermometer is indicated by a line etched on the instrument.

3. *Heating of the bath.* A pure substance may melt slowly because of the time required for the heat of fusion to be acquired from a bath only slightly warmer than the sample. During this interval the temperature of the bath may rise and the substance may appear to melt over a range of several degrees. Similarly, the acquisition of the heat necessary to raise the temperature of the thermometer is not an instantaneous process. Hence the temperature of the thermometer may be appreciably below that of the bath while the latter is being heated. To avoid these errors the rate of heating should be sufficiently slow to prevent a lag in the thermometer and to allow the substance to melt completely while the bath changes not more than 0.5° in temperature. In practice the rate of heating, when the temperature is in the neighborhood of the melting point, should not be greater than one degree per minute, and if the flame is removed when melting occurs the temperature should not rise more than a half of one degree. When the melting point is unknown, time

may usually be saved by first getting an approximate melting point quickly, and then repeating the operation, heating rapidly until the melting point is approached and then heating slowly until melting occurs.

Behavior on melting. A pure substance melts completely at constant temperature, but the *time* necessary for the process may vary, depending upon the nature of the crystals, their size, and the amount of substance. To make this time as short as possible a small amount of substance should be used, and it should be finely powdered and well packed down in a thin-walled capillary tube, so that a minimum amount of heat is necessary for fusion and the transfer of this heat from the bath to the powder is as rapid as possible. Under these circumstances a true melting point of a pure substance may be ascertained within half a degree.

An impure substance melts over a range of temperature, and this may appear to be the case for a pure substance if melting is preceded by decomposition. The term *sintering* is used to denote a cohesion of the powder, which is due to slight liquefaction before the true melting point is reached. Both sintering and melting over a range of temperature are indicative of decomposition or of the presence of impurities. If the character of the melting point and the actual temperatures involved are not changed by recrystallization of the sample, that behavior may be cited as a characteristic of the substance. The reported data should give not only the temperature as read at a given instant, but a description of how the substance behaves as the bath is heated through a certain range of temperature or is allowed to stand at a given temperature. The following expressions are suggestive: "Melts sharply at 90.0°"; "Melts from 70°–71°"; "Melts slowly at 70°–72°"; "Discolors at 70°, sinters and melts 71°–73°"; "Melts with decomposition sharply at 75°".

The procedure used here determines the melting point only indirectly. A time factor is involved. Reference should be made to other works for more elaborate methods of determining melting and freezing points which involve a certification of equilibrium between liquid and solid.

Effect of impurities on the melting point. If the impurity is soluble in the liquid phase, the melting point will be lowered and usually rendered indefinite. However, sharpness of melting point is not an absolute criterion of the absence of impurities, since eutectic mixtures melt at constant temperatures. To compare two samples in melting points, place both in the same bath at the same time and observe the *difference* in melting behavior.

The lowering of the melting point by impurities may be used to show the probable identity or difference of two samples whose individual melting points are the same or close together. A mixture of the two, if they are identical, will have as its melting point a temperature identical with or between those of the individual samples. But if they are different substances, each will constitute an impurity with respect to the other and the melting point will be lowered, unless they combine to form a new compound, in which case the melting point may be either raised or lowered. Such comparisons should be made in the same bath at the same time.

Decomposition points. The time factor may be very serious in getting reproducible decomposition points. If the substance decomposes only on melting, and the bath can be held two degrees below the melting point for several minutes without obvious change, then the decomposition temperature is very definite. More often the decomposition starts slowly ten or twenty degrees below the melting point, so that the melting and decomposition proper have the characteristics of an impure compound melting over a range of several degrees. Decompositions are not reversible, and, to be useful, a description of the decomposition should include the temperature of the bath at the time of initial immersion, the temperature range, and the duration of exposure to the bath.

THE CALIBRATION AND USE OF THERMOMETERS

A mercury thermometer is empirically calibrated by immersing it in a bath of known temperature and marking the height of the thread of mercury. There are two types of thermometers calibrated in this way, the total-immersion thermometers and the partial-immersion thermometers. The former are calibrated with the *whole* of the mercury in the constant-temperature bath at every calibration. The latter are immersed to a given point (usually three inches) only, so that at the higher temperature a longer column of mercury is outside the bath. Hence the reading of any thermometer is valid only if it is being used under the condition of its calibration.

Many thermometers are inaccurately marked (reading consistently high or low), and the calibration then takes the form of a correction to be applied to the scale reading.

If a total-immersion thermometer is used under such circumstances that a part of the mercury column is outside the bath, the thermometer reading will be in error because part of the mercury is warmer or cooler than it was at the time of calibration. It is then necessary to apply a "stem correction." The correction is given by the equation

$$\Delta t = N(t - t') \cdot 0.000154.$$

N is the length of stem, measured in degrees, which is not in the bath; t is the observed temperature; t' is the average temperature of the mercury in the exposed portion (determined by a second thermometer hung beside the first); 0.000154 is the coefficient of apparent cubical expansion of mercury in glass; and Δt is the correction to be added to or subtracted from the observed temperature.*

When a partial-immersion thermometer is used it should be immersed to the indicated depth.

Standard for calibration of thermometers. The most satisfactory method is to immerse a thermometer of known calibration, together with the uncalibrated one, in a large liquid bath and note the difference in temperature as registered by the two instruments. Standard thermometers for this purpose can be purchased from manufacturers of precision instruments, and when necessary the United States Bureau of Standards will check the accuracy of the calibrations.

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* Unless otherwise specified, all temperatures listed in this book refer to the centigrade scale.

The following table gives a list of substances of known boiling and melting points and of easy purification which can be used to calibrate thermometers. Inconsistent and erroneous results will be obtained, however, unless the greatest care is exercised in applying the theory as well as the practice of the method used.

SUBSTANCE	CORRECTED BOILING POINT*	SUBSTANCE	MELTING POINT
Chloroform	61.3°	Naphthalene	80.8°
Benzene	80.2°	Phenanthrene	101.0°
Water	100.0°	Benzoic acid	122.5°
Ethylene bromide	131.2°	Anthracene	218.0°
Bromobenzene	155.5°	Carbazole	247.0°
Nitrobenzene	210.9°	Anthraquinone	285.0°
Benzophenone	305.9°		

METHODS OF DRYING

Solids. Several processes are available for removing water from a solid substance, some of which are applicable also to the removal of volatile components other than water. If the solid to be dried is neither decomposed nor appreciably vaporized at moderately high temperatures, the drying can be accomplished in a comparatively short time by heating the sample in a drying oven. Many substances are so volatile or so readily decomposed by heat that drying must be accomplished at comparatively low temperatures. In such a case the sample is placed in a desiccator (Fig. 26) with a suitable drying agent and allowed to remain until it reaches a constant weight. A drying agent is a substance which absorbs water (liquid or vapor), forming a compound or a solution from which water escapes less readily than from the compound to be dried. The vapor pressure of pure water at 20° is 17.4 mm.; at the same temperature the pressure of water vapor over a saturated solu-

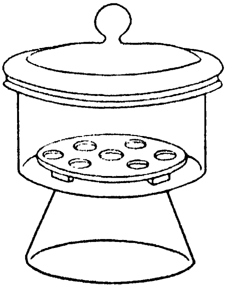

FIG. 26

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* See page 36.

tion of potassium hydroxide is 10.6 mm. The pressure of water vapor in equilibrium with 85 per cent sulphuric acid at 20° is only 0.14 mm., and it is much less than this over 95 per cent sulphuric acid. A substance may be dried, therefore, by placing it in a closed chamber with concentrated sulphuric acid. As long as the sample has a water-vapor pressure greater than the partial pressure of water vapor in the air, the process of drying is accomplished more rapidly in the air than in an ordinary desiccator, for the removal of the water vapor is aided by currents in the air. Very rapid evaporation can be accomplished by passing a stream of dry air over the moist sample. In a desiccator the air is still, and moisture is removed from the sample only as rapidly as the water vapor can pass by diffusion from the surface of the sample to the surface of the desiccant.

The condition of equilibrium or of equal vapor pressure over the substance to be dried and the desiccant is attained more rapidly in a vacuum desiccator (Fig. 27). The aqueous vapor pressures from the different substances are not changed by the removal of the air from the closed system, but the rate of diffusion of the vapor is increased by the removal of interfering air molecules, and the drying agent acquires the moisture in a shorter time. The rate at which equilibrium is approached may also be increased by an elevation of temperature, since the rate of volatilization of the water is thereby increased.

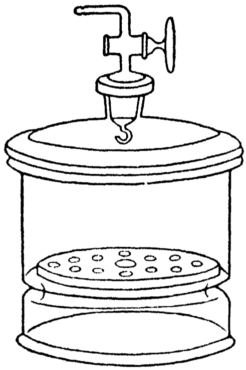
FIG. 27

There are many practical applications of the principles of desiccation where the rate of evaporation must be carefully controlled. Thus, in the commercial process of drying fruits the humidity as well as the temperature of the air used must be controlled so that moisture may not evaporate from the surface of the fruit faster than it diffuses from the interior to the surface. Rapid drying results in the formation of a hard, impervious surface crust over a moist interior.

Some common drying agents are phosphorus pentoxide, calcium oxide, sulphuric acid, soda lime,* sodium, potassium hydroxide, zinc chloride, calcium chloride, and oxalic acid. Of these, phosphorus pentoxide, sulphuric acid, soda lime, and calcium chloride are best adapted to use in desiccators.

Although the discussion of desiccation has been confined to the removal of water, the same principles apply to the removal of any volatile component of a mixture. Thus, ammonia and volatile amines may be absorbed by sulphuric acid. Ether, alcohol, or acetone may be removed from crystals by placing the crystals in a desiccator over concentrated sulphuric acid. Paraffin shavings or vaseline may be used to absorb benzene. Halogen acids, evolved by hydrolysis from some moist substances, may be taken up by soda lime.

Liquids. Fractional distillation constitutes a drying process when one of the components of the mixture is water. It is most effective in the separation of liquids that differ greatly in boiling points and that do not form constant-boiling solutions. Water can be removed completely from glycerine (b. p. 290°) and from methyl alcohol (b. p. 66°). Complete separation of water and ethyl alcohol cannot be accomplished by distillation alone, for a solution containing 95.5 per cent alcohol and 4.5 per cent water has a higher total vapor pressure, and therefore a lower boiling point, than pure water, pure alcohol, or any other mixture of the two.

Distillation often results in the removal of very small quantities of water, even if the water constitutes the higher-boiling component. This is generally true when the principal component is one in which water is very slightly soluble. Thus, if ether or benzene contains water in insufficient quantity to form two layers, the vapor phase in equilibrium with the liquid will be richer in water than is the original liquid mixture. The water in such a mixture has nearly as great an escaping tendency as it has from pure water.

The addition of a third component in which water is sparingly soluble often facilitates the removal of water by distillation.

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* Soda lime is a mixture of sodium hydroxide and calcium hydroxide. On account of its porosity it is superior to either of the separate components in its capacity to absorb carbon dioxide and water.

Thus, if benzene is added to alcohol containing a little water, the water is readily removed by distillation. Alcohol, water, and benzene can be mixed in such proportions as to give a minimum boiling point (64.8°). If, therefore, any mixture containing the three components is distilled with a good fractionating column, the minimum boiling ternary mixture will constitute the distillate until one component has disappeared. If the quantity of water is small as compared with the other components, it will be the first to disappear in spite of its relatively high boiling point. A practical application of this principle has been made in the preparation of some esters.*

To remove small quantities of water from organic liquids a solid drying agent is generally added, and the mixture is shaken for a while or allowed to stand for a longer time. The rate of dehydration may be increased by heating the mixture, but the extent of drying is often thereby reduced, owing to an increase in the vapor pressure of the drying system. When heating is desirable, the container is not closed but is connected with a reflux condenser the upper end of which is provided with a calcium chloride tube to prevent the absorption of moisture from the air (see Absolute Alcohol, p. 64). If, on treatment with a solid drying agent, an aqueous layer separates, the latter should be removed and more of the anhydrous drying agent should be used. After a liquid has been dried by contact with a solid drying agent, it should be separated from the suspended solid by filtration or decantation, then distilled to free it from dissolved solid matter or from particles that were small enough to pass through the filter and from the last traces of water. If the partially hydrated drying agent does not yield water at an appreciable rate at the boiling point of the dried liquid, the distillation can be made without removing the solid phase. Thus, alcohol can be distilled from solid calcium hydroxide without appreciable decomposition of the hydrate. Nitrobenzene must be removed from calcium chloride before distilling, for at the boiling point of nitrobenzene hydrated calcium chloride yields water.

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* Taylor, Proceedings of the Royal Society of Edinburgh, 1905, p. 831. Gibson, Proceedings of the Royal Society of Edinburgh, 1908, p. 703.

Choice of drying agent. The character of the substance to be dried determines, within certain limits, the choice of a drying agent. Sodium is used to dry ether because it reacts with water and not with ether. It is not used to dry alcohol, because it reacts with both components of the mixture. Soda lime would not be used to dry an acid, nor would phosphoric anhydride or sulphuric acid be employed to dry an amine.

Gases. A gas may be dried by passing it over the surface of a solid or liquid drying agent or by allowing it to bubble through a liquid which absorbs water. Common forms of drying tubes are shown in Figs. 28 and 29. The first is an ordinary calcium chloride tube. To hold the anhydrous granular solid dehydrating agent in place and to act as a screen for the retention of solid particles, plugs of cotton or of silk floss or of glass wool are inserted in the ends of the tube. Fig. 29 represents a U tube which may be used as a container for any type of drying agent. When used as a container for sulphuric acid, it is filled with glass beads, and enough acid is added to form a film on the surface of the beads and to seal the bend in the tube with liquid. When used with phosphorus pentoxide, glass beads covered with the solid material are introduced into the tube. The beads maintain a porous structure in the tube and increase the surface of the drying agent exposed to the gas.

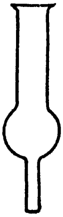

FIG. 28

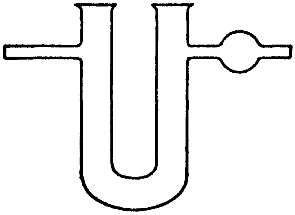

FIG. 29

The rate of drying depends upon the temperature, the surface exposed, the rate of diffusion, and the rapidity with which the drying agent takes up water. Vapor pressure depends upon temperature only. The vapor pressures of a few mixtures commonly used for drying purposes are given in the following table:

VAPOR PRESSURES

COMPOSITION OF MIXTURE	TEMPERATURE	VAPOR PRESSURE
Al_2O_3	25°	0.003 mm.*
$Mg(ClO_4)_2$	25°	Less than 0.001 mm.*
P_2O_5	25°	Less than 0.0001 mm.*
NaOH (fused)	25°	0.15 mm.*
KOH (fused)	25°	0.002 mm.*
$K_2CO_3 \cdot 1\frac{1}{2} H_2O$ K_2CO_3	25°	1.1 mm.
$CuSO_4 \cdot 5 H_2O$ $CuSO_4 \cdot 3 H_2O$	20°	5 mm.
$CuSO_4 \cdot H_2O$ $CuSO_4$	25°	0.8 mm.
$CaCl_2 \cdot 6 H_2O$ $CaCl_2 \cdot 4 H_2O$	20°	3.8 mm.
$CaCl_2 \cdot 4 H_2O$ $CaCl_2 \cdot 2 H_2O$	20°	2.5 mm.
$CaCl_2$ (granular)	25°	0.15 – 0.25 mm.*
$(COOH)_2 \cdot 2 H_2O$ $(COOH)_2$	15°	1.15 mm.
H_2SO_4 52%	20°	5.8 mm.*
73%	20°	0.85 mm.*
85%	20°	0.14 mm.*
100%	25°	0.003 mm.*
$Na_2SO_4 \cdot 7 H_2O$ Na_2SO_4	20°	13.2 mm.
$Ca(OH)_2$ CaO	301° 25°	2.6 mm. 0.08 mm.

PHYSICAL MEASUREMENTS

The organic chemist frequently finds it necessary to resort to physical measurements. The thermometer, the barometer, and the analytical balance are among the commonest physical instruments, and it is assumed that the student understands the use of these mechanical tools. There are other instruments of great value that are not in daily use. Space is not available here for descriptions and directions for using such instruments. The following references will be useful to students who are interested in the theory and technique of determining some of the more important physical constants:

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* The dehydrating capacities of some of these substances depend upon their state of aggregation or porosity, and in some other cases definite phase relationships for the different hydrates are unknown or masked by the formation of solid solutions. The numbers marked * are approximate measurements of the vapor pressures of water over particular preparations of the respective materials, and are not to be considered as the exact vapor pressures of water in equilibrium with solid or liquid phases of definite composition. A summary of the relative efficiencies of various drying agents, with literature references, may be found in a short article by J. H. Yoe, *Chemical News*, **130**, 340 (1926).

Optical rotation

HOUBEN-WEYL. Die Methoden der organischen Chemie, Vol. II. Leipzig, 1921.

LANDOLT. Optical Rotation of Organic Substances. Chemical Publishing Company.

WILEY. Principles and Practice of Agricultural Analysis, Vol. III. Chemical Publishing Company.

Absorption spectrum

BALY. Spectroscopy. Longmans, Green & Co., 1924.

EISENLOHR. Spectrochemie organischer Verbindungen. Stuttgart, 1912.

HENRI. Études de Photochimie. Paris, 1919.

HOUSTON. A Treatise on Light. Longmans, Green & Co., 1924.

Boiling-point and freezing-point determinations

COTTRELL. "The Determination of Boiling Points of Solutions." *Journal of the American Chemical Society*, **41**, 721 (1919).

MENGE. "Melting-Point Determinations," *Bulletin No. 70*, United States Hygienic Laboratory, 1910.

WASHBURN. Physical Chemistry. McGraw Hill Co.

Refractive index

ALLAN. Commercial Organic Analysis. P. Blakiston's Son & Co.

FINDLAY. Practical Physical Chemistry. Longmans, Green & Co.

WILEY. Principles and Practice of Agricultural Analysis. Chemical Publishing Company.

Colorimetric analysis

SNELL. Colorimetric Analysis. D. Van Nostrand Company.

Microscopic analysis

CLARK. Practical Methods in Microscopy. D. C. Heath & Co.

Molecular-weight measurements

COHEN. Practical Organic Chemistry. The Macmillan Company, 1920.

HOUBEN-WEYL. Die Methoden der organischen Chemie, Vol. V.

LASSAR-COHN. Arbeitsmethoden für Organisch-Chemische Laboratorien. Leipzig, 1923.

LEWIS. A System of Physical Chemistry, Vol. II. Longmans, Green & Co.

OSTWALD-LUTHER. Physiko-Chemische Messungen. Leipzig.

Density

OSTWALD-LUTHER. Physiko-Chemische Messungen. Leipzig.

TRAUBE. Physico-Chemical Methods. P. Blakiston's Son & Co.

Magnetic rotation

DUFF. Textbook of Physics. P. Blakiston's Son & Co.

INGERSOLL. Magnetic Rotations of Various Liquids in the Short Infra-Red Spectrum. *Journal of the Optical Society of America,* **6,** 663 (1922).

Solubility

HILDEBRAND. Solubility. Chemical Catalog Company.

KAMM. Qualitative Organic Analysis. John Wiley & Sons, Inc.

MULLIKEN. Identification of Pure Organic Compounds. John Wiley & Sons, Inc.

SEIDELL. Solubilities of Inorganic and Organic Compounds. D. Van Nostrand Company.

Determination of hydrogen ions

CLARK. Determination of Hydrogen Ions. The Williams & Wilkins Company.

PART II. ORGANIC PREPARATIONS

DISTILLATION

Distillation of a pure substance. Set up a distilling apparatus of the type shown in Fig. 12. Use a pyrex flask having a capacity of about 100 cc. Introduce into the flask 25 cc. of a pure liquid. Use benzene, carbon tetrachloride, or water. Adjust the slope of the condenser so that the burner at one end and the receiver at the other may rest on the table.

Heat the flask slowly until the liquid boils. Note the rise of the vapor in the flask as detected by the ring of condensing vapor, and maintain boiling at such a rate as to cause the vapor to rise slowly to the height of the thermometer bulb. Remove the flame temporarily or lower it to prevent the vapor from passing through the outlet, but keep the thermometer bulb immersed in the vapor until the initial rapid rise of the thermometer is over and the reading is almost constant. Increase the heating slowly and note the temperature as the vapor begins to leave the flask. For a low-boiling liquid this operation will require a very small flame. To prevent superheating of the vapor, avoid the use of a flame so large that the free flame comes in contact with the flask above the surface of the liquid. Continue the distillation at a steady rate of two or three drops per second. Note the thermometer reading during the operation. Near the end of the distillation prevent superheating by keeping the flame constantly in motion and making certain that vapor continually condenses on the thermometer bulb. Do not attempt to distill over all of the liquid.

Repeat the distillation, using the same material and a small, steady flame. Record the time of heating and the corresponding temperatures. Plot the results and compare the diagram with Fig. 6. The significant parts of the curve involve a possible lag in the thermometer at the beginning of the distillation and the constancy of composition of the vapor during the distillation.

What is the boiling point of the initial distillate? Was there any evidence of impurities in the supposedly pure liquid? Do your results warrant a statement regarding the boiling point of the liquid with which you started? Explain your answer.

Could you detect the presence of 1 cc. of acetone in 50 cc. of water with this procedure and apparatus? Try it and construct the plot as above. If you fail, suggest a reason for the failure.

Could you determine the approximate boiling point of a solution of salt in water by carrying out a distillation as outlined above? of a solution of alcohol in water? of a pure substance? Explain.

Fractional distillation of a known binary mixture. Obtain from the storeroom 50 cc. of 50 per cent alcohol. By fractional distillation this may be separated into an alcohol fraction, distilling at a constant temperature, and a pure-water fraction. The alcohol fraction contains 95.5 per cent alcohol and 4.5 per cent water, and under 760 mm. pressure boils at 78.17°. Pure alcohol boils at 78.30°. Between the constant-boiling mixture and the pure-water fraction there will be a small amount of a mixture of variable composition. The separation of a mixture of two liquids into two constant boiling fractions by distillation is never quantitative. With the apparatus and materials used in this experiment the intermediate fraction containing both components may be as much as 10 cc. and the distillation temperatures of the first and last fractions may be considered constant if they distill within ranges of two degrees.

Distill the 50 per cent alcohol, using the same type of apparatus and procedure as in the previous experiment. Record the time of heating and the corresponding temperatures and construct the distillation curve. The rate of distillation should be as nearly constant as possible. Have ready three clean, dry Erlenmeyer flasks to be used as receivers. With this known mixture change the receivers arbitrarily when the distillation temperature reaches 85° and 96° and measure the volume of each fraction. From your distillation curve determine (1) the probable presence of traces of very low-boiling impurities and (2) the probable distillation temperatures of the constant-boiling fractions. The accumulated residues may later be distilled and used to increase the yield of the high-boiling fraction.

Redistill fraction I, discarding any low-boiling impurities (or, in case of doubt, discard the first few drops). Note carefully when the temperature becomes nearly constant, and stop the distillation when the temperature has risen two degrees. Add fraction II to the distilling flask and collect in the same receiver any portion that distills within the two-degree range noted above. Change the receiver without stopping the distillation, and collect the variable portion up to a temperature two degrees below the temperature at which the second constant-boiling fraction is expected. Then stop the distillation, add fraction III, and continue the distillation. Change the receiver when the temperature has again reached the point two degrees below the higher constant-boiling point, and collect the last fraction over a range of two degrees. If a mistake has been made in judging from the distillation curve the points at which to expect constant temperature of distillation, it may be necessary to collect fractions over a wider range than two degrees. In this case redistill each fraction, using revised figures for a more accurate separation of the constituents.

Record in tabular form the distilling range and amount (in cubic centimeters) of each fraction in the successive fractionations.

Which was recovered in the larger amount: the water or the alcohol? What was the total percentage loss of all material?

Fractional distillation of an unknown mixture. Procure from the storeroom an unknown mixture and obtain from it two pure components. The amount of each will depend upon the distilling range and the composition of the mixture. After the preliminary distillation has been made as described below, consult the instructor as to the distilling range to be allowed each pure fraction in order to insure a reasonable yield with a fair degree of purity.

Weigh four clean Erlenmeyer flasks which are provided with corks and labels, and record each weight on the label. In one of these flasks weigh the original sample, and then proceed with the preliminary distillation in the apparatus used in the previous experiment. Record the data necessary to construct a distillation curve and use your own judgment as to the number of fractions to be taken during the first distillation. Use the tared flasks as receivers and weigh each fraction to 0.5 g. Record the boiling ranges and weights in tabular form in your notebook.

From the data obtained determine the advisability of using a fractionating column for part or all of the succeeding fractionations.

In order to effect a more complete separation of the components redistill the separate fractions, using a system similar to that used in the case of alcohol and water. Label each pure sample with the temperature range over which it distilled, the barometric pressure, and the amount in grams, and submit it to the instructor. Calculate the approximate percentage composition of the original sample, assuming the small variable fractions to have the same composition as the original. Calculate the total percentage loss during the distillation. Determine the cause of the loss.

CRYSTALLIZATION

Obtain from the storeroom an unknown for crystallization. It will be either a crude commercial product from which the chief component is to be obtained in a pure state, or a mixture of two compounds from which each is to be recovered. The instructor will specify the requirements and the permissible limits in deviations from the true melting points of the purified products.

Using very small quantities of the sample (0.1 g. for each test), determine roughly its solubility in some of the common solvents and select one that satisfies the requirements specified on page 29. Weigh the sample; treat it with enough of the hot solvent to dissolve the major portion of it and filter the solution before allowing it to cool.

To avoid precipitation in the filter it is often necessary to use a heated filter. A water-jacketed funnel is satisfactory (see page 28). The necessity of heating during the process of filtration can generally be avoided by filtering rapidly, with the aid of suction, through a preheated Büchner funnel or Gooch crucible.

A Gooch crucible should be used when a small volume is to be filtered or when a small residue is to be collected. In the former case (a small volume of solution) a test tube may be placed in the filter flask to catch the filtrate (Fig. 19). If crystals precipitate from the solution in the filter flask, redissolve them by heating the mixture and transfer the hot solution to a beaker, an evaporating dish, or any other container from which crystals may be easily removed. Rapid cooling or rapid evaporation will result in the formation of small crystals, and small crystals usually occlude very little mother liquor. Stirring during the process of crystallization likewise promotes the formation of small crystals. If crystallization does not start spontaneously when the solution is cooled, the process may usually be started by shaking or stirring the solution. Occasionally it is necessary to inoculate the supersaturated solution with a small amount of the powdered solute.

Separate the crystals from the mother liquor by filtration. This is best done with a Büchner funnel or a Gooch crucible, for they permit the use of suction and thereby facilitate the removal of mother liquor from the crystals. The filter paper should be large enough to cover the bottom of the funnel or crucible, but it must be small enough to lie flat. The paper should be moistened with the solvent and drawn down by suction before the crystals are transferred to the filter. After the mother liquor has been drawn from the crystals as completely as possible, disconnect the flask from the pump while the pump is running. Break up the matted mass of crystals with a stirring rod and moisten the crystals with a few drops of the pure solvent. Press the crystals down on the paper with a spatula or with a flat-topped glass stopper and apply suction again. It is often advisable to wash the crystals finally with another solvent, — one in which the first solvent is miscible but in which the crystals will not readily dissolve. An advantage is gained by this procedure when a very volatile solvent is substituted for one that evaporates slowly. Dry the crystals by one of the methods outlined under Methods of Drying (p. 42). Determine the melting point of the dry crystals (see page 37). Recrystallize a small portion of the product, dry it, and redetermine the melting point. If the melting point has changed, recrystallize the entire crop. When the melting point is sharp and when it is constant (that is, not changed by recrystallization), it may be assumed that the product is pure or at least as pure as it can be made by this procedure.

If the yield obtained does not represent a satisfactory recovery of the material, evaporate the mother liquor to a small volume and obtain another crop of crystals. Care must be taken to avoid evaporation to such an extent that contaminating substances are deposited on the crystals of the compound being purified. If crystals cling to the evaporating dish at the surface of the liquid, push them down into the liquid to wash them with the solvent before filtering. If they are colored by contaminating substances, redissolve them in the pure solvent, and decolorize the solution by boiling it with animal charcoal (see page 32). Filter the hot solvent (without suction if necessary, to avoid carrying charcoal through the paper) and obtain the crystals on cooling as before.

Place the dry purified product in a small labeled test tube. Record on the label the weight of the crude product, the weight of the purified product, and the melting point of each.

QUALITATIVE TESTS FOR ELEMENTS

The usual methods of qualitative analysis are not directly applicable to organic compounds, since these compounds, as a rule, do not ionize. Consequently, as a preliminary step, carbon compounds are decomposed in such a way as to form simple substances which can be detected by the usual methods. When an organic compound is oxidized at a high temperature the carbon of the compound is converted into carbon dioxide and the hydrogen into water. By fusing with sodium the nitrogen of the compound is converted into sodium cyanide, the sulphur into sodium sulphide, and the halogens into sodium halides. If nitrogen and sulphur are both present, sodium thiocyanate is often found in the fused mass. Through fusion with sodium and subsequent oxidation with nitric acid, phosphorus in organic compounds is converted into phosphate ion.

Carbon and hydrogen. Dry 3 g. of powdered copper oxide by heating it for fifteen minutes in a porcelain crucible. Cool the powder and mix it with 0.1 g. of any dry organic compound (sugar, starch, or tartaric acid may be used). Place the mixture in a small, dry pyrex test tube. Place a one-hole cork stopper in the test tube and insert a bent glass delivery tube. The delivery tube should terminate just below the surface of a clear solution of limewater contained in a small flask. Heat the mixture in the test tube by means of a small, colorless Bunsen flame. Watch for the appearance of drops of water in the cool end of the test tube and in the delivery tube. See if the liquid droplets (supposed to be water) will restore the color of dehydrated copper sulphate. Note the precipitation of calcium carbonate in the limewater. Test the solubility of the precipitate in dilute acetic acid. Has any visible change occurred in the copper oxide?

Nitrogen and sulphur. Place a clean, bright piece of sodium (not larger than a 2-millimeter cube) in the closed end of a glass tube 3 mm. in diameter and 6 or 8 cm. long. Drop a small sample of the substance to be analyzed on the sodium and heat the end of the tube gently for a few minutes. If the substance under investigation is a liquid, allow it to reflux; that is, to condense in the cool portion of the tube and run back onto the sodium. Finally, to insure complete decomposition of the compound, heat the tube to dull redness for half a minute. Before the tube has cooled, plunge it into 10 cc. of water or of 50 per cent alcohol contained in a small beaker and immediately cover the beaker with a watch glass. The hot glass will break and the fused mass will dissolve. It is advisable to protect the eyes with goggles when breaking the tube in this manner; small pieces of burning sodium are sometimes thrown from the beaker. When the evolution of hydrogen ceases, heat the solution to boiling, then filter it through a very small wet filter paper. If the decomposition of the compound was complete, the filtrate will be colorless.

Test the filtrate with litmus. If it is not strongly alkaline in reaction, repeat the fusion, using more sodium. Place a drop of the filtrate on a clean silver coin. Is silver sulphide formed?

Divide the filtrate into four equal parts. To one portion add a drop of a freshly prepared solution of sodium nitroprusside. A violet color indicates the presence of sulphide ion. Acidify the second portion with acetic acid; then add a few drops of lead acetate solution. A black precipitate shows the presence of sulphide ion. Acidify the third portion with hydrochloric acid; then add a few drops of ferric chloride solution. A red color indicates the presence of thiocyanate ion. To the fourth portion add three or four drops of a freshly prepared saturated solution of ferrous sulphate and an equal amount of ferric sulphate. Heat the mixture to the boiling point; then cool and acidify it with dilute sulphuric acid. A blue precipitate indicates the presence of cyanide ion. If Prussian blue is not precipitated immediately, add a few drops of normal sodium fluoride and allow the mixture to stand fifteen minutes. Finally filter it and examine the filter paper. A blue residue on the paper indicates the presence of nitrogen.*

Halogens. Fuse the compound with sodium and extract the mass with water or alcohol as described above. Acidify the solution with pure nitric acid, and if the compound contained sulphur or nitrogen, boil it for a minute to expel hydrogen sulphide or hydrogen cyanide. Divide the solution into two parts. To one portion add a few drops of silver nitrate solution. A white precipitate indicates the presence of a halogen. If a halogen is present, add to the second portion of the solution an equal volume of chloroform and a few drops of chlorine water. Shake the mixture vigorously for a minute; then allow it to settle. A violet color in the chloroform layer indicates the presence of iodine. A yellow color is due to bromine. If the chloroform layer remains uncolored, the halogen present is chlorine. Prepare solutions containing traces of bromide and iodide ions. Make the chloroform test on each of these solutions and compare the colors with those produced by the unknown. Silver chloride and bromide may be separated from silver iodide by solution in ammonium hydroxide.

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* A few nitrogen compounds (including diazonium salts) decompose at low temperatures with the liberation of free nitrogen. Such compounds fail to form sodium cyanide when fused with sodium.

Phosphorus. Decompose the compound with sodium as in the test for nitrogen, or use a portion of the extract from the fusion made in the test for nitrogen or for halogens. Boil the clear extract with twice its volume of concentrated nitric acid. Cool the solution (its volume should not exceed 6 cc.) and add 10 cc. of ammonium molybdate solution. Warm the mixture on a water bath to about 60° and keep it at that temperature for an hour unless a precipitate forms in a shorter time. A yellow precipitate of ammonium phosphomolybdate indicates the presence of phosphorus in the compound. Arsenic, if present, interferes with this test.

The principal reactions involved in these qualitative tests are represented by the following equations:

$$CO_2 + Ca^{++} + 2\,OH^- \longrightarrow CaCO_3 + H_2O. \tag{1}$$

$$\left.\begin{aligned} 6\,CN^- + Fe(OH)_2 &\longrightarrow Fe(CN)_6^{----} + 2\,OH^-.\\ 3\,Fe(CN)_6^{----} + 4\,Fe^{+++} &\longrightarrow Fe_4[Fe(CN)_6]_3.\end{aligned}\right\} \tag{2}$$

$$S^{--} + \tfrac{1}{2}\,O_2 + 2\,Ag + H_2O \longrightarrow Ag_2S + 2\,OH^-. \tag{3}$$

$$S^{--} + Fe(CN)_5NO^{--} \longrightarrow Fe(CN)_5S^{----} + NO.^* \tag{4}$$

$$3\,CNS^- + Fe^{+++} \longrightarrow Fe(CNS)_6. \tag{5}$$

$$Ag^+ + Cl^- \longrightarrow AgCl. \tag{6}$$

$$2\,I^- + Cl_2 \longrightarrow I_2 + 2\,Cl^-. \tag{7}$$

$$\begin{aligned} 7\,H_3PO_4 + 12\,(NH_4)_6Mo_7O_{24} + 65\,HNO_3\\ \longrightarrow 7\,(NH_4)_3PO_4 \cdot 12\,MoO_3 \cdot 2\,HNO_3 \cdot H_2O\\ + 51\,NH_4NO_3 + 29\,H_2O.\end{aligned} \tag{8}$$

METHANE

Place 8 g. of dry sodium acetate and an equal weight of powdered soda lime in a porcelain mortar. Grind the mixture until the mass is finely divided and the components are uniformly mixed. Transfer the mixture to a large pyrex test tube. Clamp the tube in an inclined position. The open end of the tube should be slightly lower than the closed end. Attach to it a delivery tube leading to a pneumatic trough. Heat the tube with a Bunsen flame and collect the gas in test tubes over water. Moisture from the reagents condenses in the cool portion of the apparatus. The inclination of the tube prevents water from running back to the hot end. The first portion of gas that escapes is a mixture of methane and air. Methane, when free from air, burns quietly. Ignite test-tube portions from time to time and discard the product as long as an explosive mixture is obtained.

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* *Chemical Abstracts*, **9**, 3185 (1915).

Introduce 1 cc. of bromine water into each of two test tubes containing methane. Close the tubes with cork stoppers and expose one of them to sunlight. Keep the other in the dark. Compare the two at half-hour intervals during the laboratory period.

In a large test tube or a small wide-mouthed bottle mix a portion of the gas with the volume of air required for complete combustion. Assume that the air is 20 per cent oxygen. Ignite the mixture.

Determine the effect of bromine and of iodine on gasoline and on amylene in the light and in the dark.

From the formula CH_4 calculate the weight of a liter of methane under the conditions of temperature and pressure existing in the laboratory.

What weight of sodium acetate is required to yield 10 liters of methane?

The preparation of methane by this method is an example of one of the general processes of obtaining a hydrocarbon from other types of organic compounds. An alkyl halide may be reduced to a hydrocarbon by conversion to an alkyl magnesium halide and by subsequent hydrolysis (Grignard reaction). The same thing may be accomplished by treating a slightly acidified alcoholic solution of an alkyl iodide with a zinc-copper couple. Alcohols are reduced to hydrocarbons by hydriodic acid and phosphorus (Berthelot reaction) or by mixing the alcohol vapor with hydrogen and passing the mixture over hot nickel (Sabatier-Senderens reaction). The electrolysis of a salt of an acid corresponding to the formula RCOONa results, in part, in the formation of a hydrocarbon, R—R, and carbon dioxide.

ETHYLENE

Ethylene may be prepared by heating alcohol with phosphoric acid or with concentrated sulphuric acid. The first products of the reaction are esters, $(C_2H_5)H_2PO_4$, $(C_2H_5)_2HPO_4$, and $(C_2H_5)_3PO_4$ or $(C_2H_5)HSO_4$ and traces of $(C_2H_5)_2SO_4$. These esters decompose at high temperatures, yielding ethylene and phosphoric acid or sulphuric acid.

Use a 150-cubic-centimeter distilling flask *A*, a side-armed test tube *B*, or a small flask provided with a three-hole stopper, and two 150-cubic-centimeter wash bottles, *C* and *D*. The tube *B* is inserted as a trap to avoid the danger of drawing alkali back into the generating flask. It is about half full of water, and an open tube which terminates near the bottom of *B* extends far enough above the stopper to provide a head of water that will insure the passage of the gas through the wash bottles. The wash bottle *C* contains a 10 per cent solution of sodium hydroxide, and *D* contains concentrated sulphuric acid. The alkali removes sulphur dioxide, and the acid dissolves ether. A small part of the ethylene is also held by the sulphuric acid.

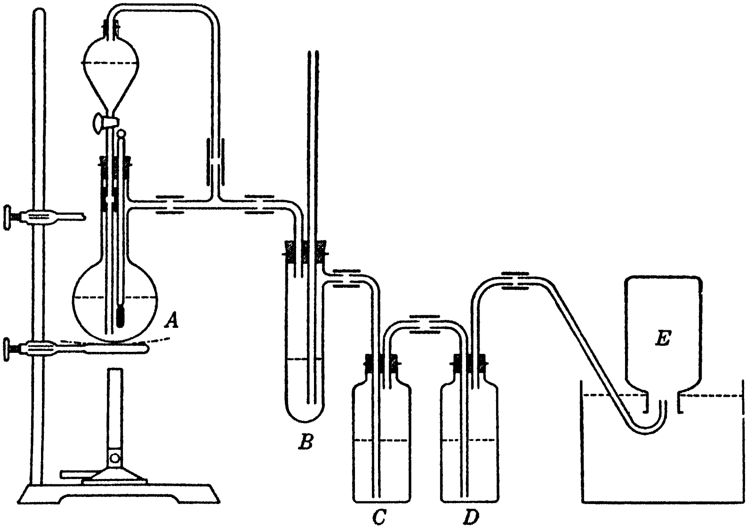

FIG. 30

Place in the generating flask a mixture of 30 cc. of 95 per cent alcohol and 50 cc. of concentrated sulphuric acid. Pour into the dropping funnel a mixture of 50 cc. of alcohol and 50 cc. of concentrated sulphuric acid. The bulb of the thermometer and the end of the stem of the dropping funnel must be below the surface of the liquid in flask *A*. To equalize the pressure and avoid the danger of having the gas discharge through the funnel, a connection is made by means of a glass or rubber tube between the top of the dropping funnel and the delivery tube. The connection is made conveniently by using a T tube ( ) between *A* and *B*.*

Heat the mixture in the generating flask on a sand bath to 150°; then admit the solution from the dropping funnel. The temperature should be kept nearly constant, and the rate of flow from the funnel should be regulated so as to maintain a steady production of gas. Ordinarily the time required for the addition of the mixture is thirty minutes.

After the air in the system has been displaced, as indicated by the quiet burning of a test-tube sample of the ethylene, collect the gas in large test tubes or in 100-cubic-centimeter bottles.

To one bottle of gas add 5 cc. of bromine water. Close the mouth of the bottle with a glass stopper or a glass plate, shake the mixture, and describe the result. Add an excess of bromine water to a bottle of ethylene, shake it for five minutes, and then add enough dilute sodium hydroxide to discharge the color of the unused bromine. Look for oily drops of ethylene dibromide in the solution.

To another sample in a glass-stoppered bottle add 5 cc. of a dilute solution of potassium permanganate (about 3 g. $KMnO_4$ per liter). Shake the mixture and record your observations.

Write balanced equations representing the reactions in these experiments.

What volume of ethylene measured over water at 25° and 740 mm. can be obtained from 50 g. of alcohol? (See Appendix for vapor pressure of water.)

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* A system such as is used in this experiment should always be tested for leaks as soon as it is assembled. In this case a leak may be detected by attaching a rubber tube to the outlet tube under *E* and applying suction until air bubbles appear in *B*, *C*, and *D*. The rubber tube is then closed by a clamp without release of the pressure, and the liquid levels in the tubes of *B*, *C*, and *D* are observed. The levels in these tubes should remain stationary, for at least a minute, at points below the levels of the liquids in the bottles. If a leak is detected, disconnect the units of the system and test each separately. Properly fitted rubber stoppers and rubber tubing will be sufficiently gas tight for this experiment.

Under what conditions can ethylene be made from ethyl iodide?

How can ethylene be made from symmetrical dibromethane?

Starting with methane, how could you prepare ethylene?

How could you prepare ethyl alcohol from ethylene?

What happens when ethylene is treated with hydrogen iodide? with anhydrous sulphuric acid? with hypochlorous acid? with hydrogen gas and finely divided nickel? Does ethylene react rapidly with chlorine? with iodine?

ACETYLENE

Place 10 g. of calcium carbide in a 100-cubic-centimeter distilling flask. Close the neck of the flask with a stopper fitted with a dropping funnel and connect the side arm with a delivery tube. From the funnel allow water to drop slowly upon the carbide. Collect the gas over water in test tubes or small bottles.

Ignite one sample.* Describe the flame. Place a few cubic centimeters of bromine water in a test tube containing acetylene. Shake the mixture. Describe the action. Write the equation.

Add to 5 cc. of a dilute (0.1 *N*) solution of silver nitrate enough ammonia to dissolve any precipitate that forms at first. Pour the solution into a test tube containing acetylene, insert a stopper at once, and shake the mixture. Give the equation. Dry silver acetylide explodes if heated or agitated. Consult the instructor with reference to experiments that may be made with the dry compound. Destroy the substance with sulphuric acid before leaving the laboratory.

Repeat this experiment, using an ammoniacal solution of cuprous chloride instead of the silver compound.

Pour 1 cc. of a dilute alkaline solution of potassium permanganate into a tube containing acetylene. Shake the mixture. Describe the result.

If the first step in the oxidation by potassium permanganate corresponds to that in the oxidation of ethylene, what products will be formed? Account for the fact that potassium oxalate is one of the products formed.

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* Do not ignite acetylene contained in a bottle or a flask unless you have determined by a test-tube experiment that the gas is free from air. Acetylene and air mixtures produce dangerous explosions.

What volume of acetylene measured at 20° and 750 mm. can be generated by the action of water on 10 g. of calcium carbide? Assume that the commercial substance is 70 per cent calcium carbide.

How could you distinguish between acetylene and dimethyl acetylene without resort to a quantitative measurement?

Suggest a different method for making acetylene, beginning with ethyl alcohol.

Devise a method for making symmetrical dimethyl acetylene.

ALCOHOLS

Alcohols are hydroxy derivatives of the aliphatic hydrocarbons. Their most characteristic reactions are due to the hydroxyl group. Methyl alcohol is a product of the distillation of wood. Ethyl alcohol is made commercially through the fermentation of sugars. Among the reactions available for the preparation of alcohols may be mentioned the following: (1) the reduction of aldehydes, ketones, and acid chlorides; (2) the action of organomagnesium halides (Grignard reagent) on aldehydes, ketones, esters, and acid halides; (3) the action of nitrous acid on primary amines; (4) the action of silver hydroxide, aqueous potassium hydroxide, or steam on halogen derivatives of the hydrocarbons; (5) the action of superheated steam in the presence of certain catalysts on unsaturated hydrocarbons; (6) the hydrolysis of naturally occurring esters.

Using small quantities of methyl, ethyl, and amyl alcohols, carry out the following experiments:

1. Determine approximately the volume of water required to dissolve 1 cc. of each alcohol.

2. Add small pieces of sodium to 2-cubic-centimeter samples of each. Identify the gas evolved. When no more sodium will dissolve, notice that colorless solid products have been formed. Write a formula for each product. Write equations representing the reactions that produced these residues. Test the action of water on each of these residues. Are the water extracts alkaline? Explain.

3. Determine by the following test whether or not alcohols are readily oxidized: To 5 cc. of a 5 per cent solution of sodium dichromate add two drops of concentrated sulphuric acid. Heat

the solution to boiling. Does heat cause any change in the appearance of the reagents? Add a few drops of an alcohol and heat again. Describe the change. Try it with another alcohol. Repeat the experiment, substituting for the alcohol a few drops of (1) gasoline, (2) acetone, (3) a sugar solution. Is the test specific for alcohols? Assuming that the alcohols are oxidized to acids without loss of carbon, write balanced equations for the reactions.

4. Mix a 3-cubic-centimeter sample of each alcohol with half its volume of glacial acetic acid and a drop of concentrated sulphuric acid. Warm each mixture over a flame and shake it vigorously for about one minute; then cool it. Add about 5 g. of ice; then neutralize the cold mixture by slowly adding solid sodium carbonate until no more gas is evolved or until the aqueous layer is alkaline to litmus. Notice the odor of the ester produced. Write balanced equations representing the formation of the esters.

Absolute alcohol. To remove traces of amines that may be present in commercial alcohol add 5 cc. of concentrated sulphuric acid to a liter of alcohol, and distill the mixture, using a steam bath.

To remove water add 300 g. of calcium oxide (quicklime*) to 1 liter of 95 per cent alcohol contained in a 1500-cubic-centimeter pyrex flask. Connect the flask with a water-cooled reflux condenser and heat it on a steam bath for twenty-four hours. Have a calcium chloride tube attached to the upper end of the condenser during this operation. Change the position of the condenser and distill the alcohol into a dry flask. Connect the receiving flask with the condenser by means of an adapter and protect the distillate from atmospheric moisture by attaching to the receiver a tube of calcium chloride. Arrange the drying tubes so that liquid condensing in them will not flow back into the condenser or receiver.

The distillate will be about 99 per cent alcohol. Add to this distillate 300 g. of calcium oxide in the form of small, clean pieces and reflux again on the steam bath for twenty-four hours.

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* The lime should be broken into small pieces but not powdered. It should be clean and fresh (not air slaked).

Distill again from the lime under anhydrous conditions as before. This time the distillate will contain less than 0.4 per cent of water. By repeating the process once more the alcohol can be brought up to 99.9 per cent or higher. In order to avoid an unnecessary loss of alcohol the final treatment should be made with a very small amount of lime. This also reduces the danger of having lime carried over with the distillate.

The second and third processes of refluxing can be eliminated if a longer time is available. Allow the 99 per cent alcohol to stand in contact with good lime in a tightly stoppered flask. Shake the mixture daily. At any time after three weeks absolute alcohol can be distilled from the flask as needed.

Absolute alcohol takes up water quite rapidly, and great care must be exercised to avoid exposure to moist air.

Commercial alcohol contains traces of other substances that are not removed by treatment with lime or sulphuric acid.*

ETHYL BROMIDE

Dissolve 30 g. of absolute alcohol in 50 g. of concentrated sulphuric acid in a half-liter distilling flask. Add the acid to the alcohol in small quantities with constant shaking. Cool the solution and add 50 g. of powdered potassium bromide. Immediately connect the side arm of the flask with a condenser. Attach an adapter to the lower end of the condenser and allow the lower end of the adapter to dip beneath the surface of water in a small flask which is packed in ice. Distill the mixture rapidly, using a sand bath.

Ethyl bromide collects as a heavy, oily liquid under the water, and loss by evaporation is thus prevented. Continue the distillation as long as oily drops appear in the condenser. Separate the ethyl bromide from the water by means of a separatory funnel. To remove ether, which contaminates the preparation, add concentrated sulphuric acid, drop by drop, with constant shaking, until the acid forms a layer under the ethyl bromide. The container must be kept in an ice pack during this operation.

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* For methods of obtaining chemically pure alcohol see Harned and Fleysher, *J. Am. Chem. Soc.*, **47**, 82 (1925), and Danner, *J. Am. Chem. Soc.*, **44**, 2832 (1922). For a more complete discussion of the problems involved in drying alcohol, and for optional methods and experimental results, see W. A. Noyes, *J. Am. Chem. Soc.*, **45**, 857 (1923).

Draw off the acid layer and wash the ethyl bromide with water, then with dilute sodium carbonate solution. Finally dry the product with granular calcium chloride and redistill it. This time the distilling flask, provided with a thermometer, should be heated on a water bath. Collect the distillate in a dry flask packed in ice and salt. Obtain a product that boils within a range of two degrees. Pure ethyl bromide boils at 39°. Yield, from 35 to 40 g.

Suggest a mechanism for this reaction that involves first a reaction between the alcohol and the sulphuric acid.

Write equations for the reactions involved in this preparation.

Assign two reasons for keeping ethyl bromide cold while removing the ether with sulphuric acid.

What is the origin of the ether?

Why is more sulphuric acid used than is required to react with the potassium bromide?

Why cannot ethyl iodide be prepared in an analogous way from potassium iodide, alcohol, and sulphuric acid? Compare the effects of concentrated sulphuric acid upon HCl, HBr, and HI.

Assuming that the acid used is 95 per cent H_2SO_4, determine which reagents were used in excess.

Suggest a different method for making ethyl bromide; specify the substances that would contaminate the product, and state how each could be removed.

Does ethyl bromide react immediately with a solution of silver nitrate? Compare its behavior in this respect with that of sodium bromide. Is ethyl chloride formed rapidly when alcohol is treated with hydrochloric acid? Compare the rate of the reaction with the rate of the reaction between sodium hydroxide and hydrochloric acid. How do you account for the difference?

ETHYL IODIDE

Place 3 g. of red phosphorus and 25 g. of absolute alcohol* in a small flask. Introduce 25 g. of powdered iodine at the rate of about 1 g. per minute. Keep the mixture well cooled and thoroughly shaken while the iodine is being added. A reflux condenser should be connected with the flask. It may be disconnected during short intervals for the introduction of the iodine. Let the mixture stand overnight with the condenser attached, or, if heat is no longer being liberated, stopper the flask loosely with a cork. Finally heat it under the reflux condenser on a water bath about half an hour. Connect the flask to a condenser and distill off the ethyl iodide. A sand bath may be used if the distillation from the water bath is too slow. Wash the product with dilute sodium carbonate solution to remove alcohol and iodine. Use enough sodium carbonate to render the water layer alkaline after shaking with the ethyl iodide. Separate the liquids by means of a separatory funnel, wash once with water, and dry the product (lower layer) over fused calcium chloride. Decant the liquid from the calcium chloride and redistill it. Collect the fraction boiling over a range of two degrees (b. p. 72.3°).*

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* For preparation of absolute alcohol see page 64.

Calculate the theoretical yield.

Account for the presence of free iodine in the distillate. In what form is it removed?

Does ethyl iodide react rapidly with aqueous silver nitrate? Is this behavior normal or exceptional? Is it the character of the reaction or its rate that is exceptional? Repeat the silver nitrate test with chloroform and with methyl iodide.

How could you convert ethyl iodide into (1) ethane? (2) ethylene? (3) butane? (4) alcohol?

How does ethyl iodide react when heated with (1) sodium ethylate? (2) ammonia? (3) trimethyl amine? (4) silver acetate?

How could you prepare a di-iodoethane ($C_2H_4I_2$) (1) with the iodine atoms on the same carbon? (2) with one iodine atom on each of two adjacent atoms?

CHLOROFORM

Make a paste of fresh bleaching powder by grinding 100 g. of the powder with 200 cc. of water. With an additional 200 cc. of water wash the paste into a two-liter flask. Add 25 cc. of acetone and connect the flask with a long water-cooled condenser. An adapter on the end of the condenser should dip just below the surface of ice water in the receiver (an Erlenmeyer flask). See that all connections are air tight except the connection between the adapter and the receiver, and then heat the mixture on a sand bath until it begins to froth. The flame should then be removed or turned low until the reaction becomes sluggish or until there is no further evidence of foaming. This may require half an hour or more. Finally distill the mixture. Collect the distillate as long as oily drops appear in the condenser.

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* Alkyl halides can be made from alcohols and saturated aqueous solutions of halogen acids. Norris and Taylor, *J. Am. Chem. Soc.*, **46**, 753 (1924). See also Conant and Kirner, *J. Am. Chem. Soc.*, **46**, 232 (1924).

To remove dissolved chlorine add to the contents of the receiver 5 cc. of a concentrated solution of sodium hydroxide. Shake the mixture and test the aqueous layer with litmus. If it is not distinctly alkaline, repeat the treatment with sodium hydroxide until an alkaline reaction is obtained. Remove the chloroform layer from the water by means of a separatory funnel. Dry the product with granular calcium chloride until it is no longer turbid. Decant the liquid into a small, dry distilling flask and redistill it (b. p. 61.2°; sp. gr. 1.499 at 15°; solubility in water, 6 parts per 1000 by weight).

The following equations represent probable steps in the reaction, but some products not indicated here are also formed.

$$\begin{aligned} CaOCl_2 + H_2O &\longrightarrow Ca(OH)_2 + Cl_2, \\ CH_3COCH_3 + 3\,Cl_2 &\longrightarrow CH_3COCCl_3 + 3\,HCl, \\ 2\,CH_3COCCl_3 + Ca(OH)_2 &\longrightarrow (CH_3COO)_2Ca + 2\,CHCl_3. \end{aligned}$$

Warm a mixture of chloroform (2 drops), aniline (2 drops), and alcoholic potash (10 drops). Keep the mixture under a hood. Note the odor. Before pouring it into the sink, destroy the product by adding concentrated hydrochloric acid and warming.

$$CHCl_3 + C_6H_5NH_2 + 3\,KOH \longrightarrow C_6H_5NC + 3\,KCl + 3\,H_2O.$$

Does chloroform react readily with silver nitrate? Is it neutral? Test its solubility in alcohol, in ether, and in benzene. Describe its taste and odor.

Chloroform slowly decomposes in air under the influence of sunlight, yielding phosgene ($COCl_2$). It reacts with alcoholic potash, yielding potassium chloride, potassium formate, and water. Write equations for these reactions.

Chloroform combines with primary amines in the presence of alcoholic potash, forming carbylamines. This reaction affords a qualitative test for a primary amine or for chloroform, since the product of the reaction is easily identified by its odor.

IODOFORM

Dissolve 25 g. of potassium iodide in 500 g. of water and add 5 g. of acetone. To this solution add a dilute solution of sodium hypochlorite,* drop by drop, as long as it continues to produce a precipitate. Keep the mixture well shaken while the hypochlorite is reacting. Allow the precipitate to settle, decant the supernatant liquid, and wash the residue with water two or three times. Separate the product from the wash water on a suction filter. Recrystallize it from hot alcohol. Determine the melting point. Yield, from 10 to 15 g.

Dissolve a crystal of iodine in 3 or 4 cc. of alcohol. Pour the solution into a test tube containing 10 cc. of a saturated solution of sodium carbonate. Warm the tube in a water bath to 75° for half an hour. Interpret the result.

What would happen if the potassium iodide were omitted in this preparation? Why is it advantageous to use sodium hypochlorite rather than bleaching powder?

How could iodoform be separated from insoluble calcium compounds if bleaching powder were used?

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* The sodium hypochlorite solution may be prepared by precipitating the calcium in 60 g. of bleaching powder with a solution of sodium carbonate. Filter and use the filtrate. A slight excess of sodium carbonate will not interfere.

The reaction probably takes the following course:

$$\mathrm{NaOCl + KI \longrightarrow NaOI + KCl,}$$
$$\mathrm{CH_3 \cdot CO \cdot CH_3 + 3\ NaOI \longrightarrow CH_3 \cdot CO \cdot CI_3 + 3\ NaOH,}$$
$$\mathrm{CH_3 \cdot CO \cdot CI_3 + NaOH \longrightarrow CH_3 \cdot COONa + CHI_3.}$$

The substitution reactions of iodine as written above involve hypoiodite ion rather than iodine, whereas in the corresponding formation of chloroform the reacting constituent is represented as chlorine. This is based upon the fact that iodine alone does not usually react with hydrocarbons to form substitution products as do bromine and chlorine. Since there is a rapid equilibrium in water solution between a halogen and the corresponding hypohalite, there is no valid evidence that the reaction takes place through the halogen or hypohalite exclusively. Hence substitution reactions of this type with any halogen may be written in either form.

Could alcohol be substituted for acetone?

Calculate the percentage of hydrogen in iodoform.

Assuming that the first step in the preparation of iodoform from alcohol and sodium hypo-iodite is the oxidation of the latter to acetaldehyde, write a series of balanced equations representing the complete process.

ETHER

To 75 cc. of absolute alcohol contained in a half-liter distilling flask add, in small quantities, with frequent shaking, 75 cc. of concentrated sulphuric acid. Place the flask on a sand bath and connect the side arm with a long water-cooled condenser. The lower end of the condenser should be fitted with an adapter which will deliver the distillate to the bottom of the receiver. Use a small distilling flask for the receiver. Pack it in ice and attach to the side arm a delivery tube to convey the escaping ether vapor to the sink or to the hood or to some other place far away from the nearest flame. On account of the inflammability and volatility of ether, care must be taken to have all joints of the apparatus tight. No flame is to be brought into the neighborhood of the liquid, and it should not be distilled over a free flame.

Close the neck of the distilling flask with a two-hole stopper. Insert a thermometer through one hole and immerse the bulb of the instrument in the liquid mixture of alcohol and acid. Insert the stem of a dropping funnel in the other hole of the stopper. It is desirable but not necessary to have the stem of the funnel extend nearly to the bottom of the flask (below the surface of the liquid). Apply heat enough to raise the temperature of the mixture to 140°. Then introduce, drop by drop, 200 cc. of alcohol (95 per cent) and maintain a temperature of from 140° to 145° during the entire operation.

Pour the distillate into a separatory funnel and shake it with a volume of 10 per cent sodium hydroxide solution sufficient to remove the sulphurous acid which is formed through reduction of some of the sulphuric acid by hot alcohol. Separate the layers. Transfer the ether layer to a small distilling flask and add to it slowly, and with constant shaking, about one tenth of its own volume of concentrated sulphuric acid. Distill it once more from a water bath. The product still contains traces of alcohol and water. Place two or three grams of sodium wire in the ether, and after the effervescence ceases redistill it, using the same precautions as before. Ether boils at 35°. If a sodium press is not available, thin slices of the metal may be substituted for the wire. Be sure to destroy the sodium residue by dissolving it in alcohol before discarding it.

Give evidence that ethyl hydrogen sulphate ($C_2H_5HSO_4$) is an intermediate product when this method is employed for making ether. How would you proceed to make the mixed ether, $CH_3—O—C_2H_5$?

Could other dehydrating agents be substituted for sulphuric acid in this preparation?

In the preparation of ethylene from alcohol and sulphuric acid, how is the formation of ether inhibited?

How is ethyl potassium sulphate made?

How is diethyl sulphate prepared?

What is the solubility of ether in water? of water in ether?

To dry a large volume of ether add to it about half its volume of porous solid calcium chloride and allow the mixture to stand several days. Decant the ether into a dry bottle and add sodium wire. When the evolution of hydrogen ceases, distill the ether from the sodium. On a commercial scale ether is freed from water and alcohol by distilling it through a tower containing solid potassium hydroxide.

FORMALDEHYDE

Oxidation of an alcohol. A small flask *A* (Fig. 31) containing 50 cc. of methyl alcohol is fitted with a two-hole stopper and immersed in a water bath at a temperature of from 40° to 45°. A glass tube passing through the stopper terminates near the bottom of the flask (below the surface of the alcohol). A delivery tube leading from the flask is connected with a pyrex glass tube about 20 cm. long and 1 cm. in diameter. The latter is inclined slightly to prevent alcohol, which may condense, from flowing into the heated part of the tube. A loose plug of asbestos 1 cm. long and a roll of oxidized copper gauze 6 or 8 cm. long are placed in the tube. The exit end of the tube is attached to an adapter or a delivery tube which passes through a one-hole stopper in a filter flask *B* and terminates under water near the bottom of the flask. The side arm of the filter flask is attached to a water pump or an aspirator, so that a steady stream of air can be drawn through the apparatus.

To test the apparatus for leaks, draw air through the apparatus until bubbles appear in *A* and *B*; then clamp the exit tube and disconnect the pump and see if the liquid levels in the two tubes remain constant. If air tight, remove the pinch clamp, attach *B* to the suction pump, and apply a flame to the pyrex tube under the copper gauze until the gauze acquires a dull red heat. Maintain this temperature and continue to draw air through the system until most of the alcohol has evaporated. By a proper adjustment of the temperature of the water bath and the rate of flow of air through the system it is possible to obtain an almost quantitative oxidation of the alcohol. Under such circumstances the heat of the reaction is sufficient to maintain the copper gauze at red heat without the continued use of the flame.

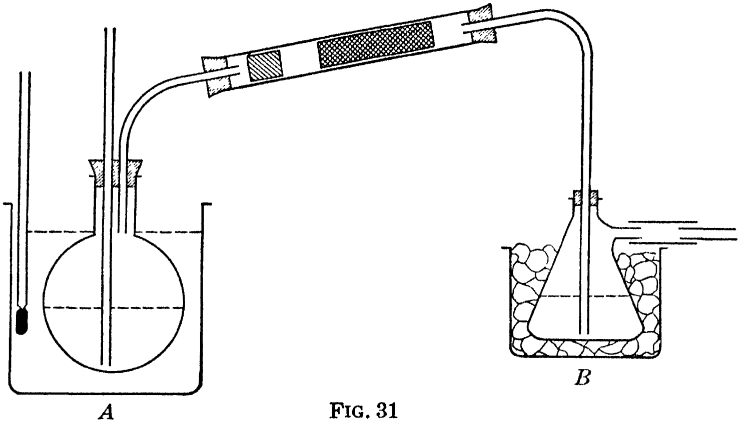

FIG. 31

$$CH_3OH + \frac{1}{2}O_2 \longrightarrow HCHO + H_2O.$$

It is advisable to wear goggles to protect the eyes, for in rare instances the mixture of alcohol vapor and air explodes when heated. The purpose of the asbestos plug is to minimize this danger. It tends to prevent the flame from striking back to the flask. A short roll of iron gauze would serve the purpose equally well.

Test 2-cubic-centimeter portions of the solution with equal volumes of (1) hot Fehling's solution,* (2) a cold ammoniacal solution of silver oxide (Tollen's reagent).

To 2 cc. of magenta solution which has been decolorized by sulphur dioxide (Schiff's reagent) add a few drops of the formaldehyde solution. Color should develop within two minutes without the application of heat.†

Evaporate 20 cc. of the solution on the steam bath. What is the residue?

Evaporate 20 cc. of the solution after adding an equal volume of concentrated ammonium hydroxide. If during evaporation the odor of ammonia disappears, add a little more from time to time. Recrystallize the product from hot alcohol. Describe it. Is this a general reaction of aldehydes or is it characteristic of formaldehyde? This product, commonly called urotropine, can be hydrolyzed in acid solution to formaldehyde and ammonium ion.

To 2 cc. of formalin (40 per cent formaldehyde) add an equal volume of a freshly prepared concentrated solution of sodium hydrogen sulphite. Describe the product and prove that it contains formaldehyde. Write an equation for the reaction.

Obtain from the storeroom 15 cc. of a 10 per cent solution of acetaldehyde. Repeat the experiments with magenta, silver oxide, and Fehling's solution, using acetaldehyde.

To 5 cc. of acetaldehyde solution add 1 cc. of a concentrated solution of sodium hydroxide. Warm the mixture. Describe the result. Does formaldehyde behave in the same way in the presence of alkali?

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* For the preparation and use of Fehling's solution see the Appendix, p. 303, and the footnote on page 177. Tollen's reagent should be used cold when employed as a test for an aldehyde, since, when heated, it oxidizes many other types of compounds. Fehling's solution should be heated by immersing the test tube containing the reagents in boiling water. With either Fehling's or Tollen's reagent the time required for the reaction should be noted (see page 172).

† Heat alone will restore the color of the magenta by expelling SO_2. The restoration of color by an aldehyde is not due simply to removal of SO_2 (see page 170).

Assuming that the air becomes completely saturated with methyl alcohol and that the air and alcohol acquire the temperature of the water bath, calculate the partial vapor pressures of oxygen and alcohol in the flask (consult Appendix for the vapor pressure of alcohol and assume a barometric pressure of 760 mm.).

If the temperature of the vapors is 10° below that of the water bath, is the ratio between oxygen and alcohol molecules nearer to the theoretical value for the production of formaldehyde or is there a greater excess of one reagent?

ISOVALERIC ACID

Oxidation of an alcohol. In a one-liter pyrex flask mix 100 cc. of isoamyl alcohol, 200 cc. of water, and 90 g. of powdered sodium dichromate. Prepare a mixture of 100 cc. of sulphuric acid and 100 cc. of water. (Pour the acid into the water very slowly and keep the solution vigorously shaken until all of the acid has been added.) Cool the acid solution; then add it in 10-cubic-centimeter portions to the alcohol-dichromate mixture. Shake the mixture after each addition of acid and cool the flask by immersion in water if it gets too hot to be held comfortably in the hand. After all the acid has been added and the flask no longer gets hot when shaken, connect the flask with a steam generator and a water-cooled condenser. On account of the bad odor of the acid produced this experiment should be done under a hood or in the open-air laboratory. Distill with steam as long as oily drops appear in the condenser. The distillate forms two layers. The upper layer is an ester, isoamyl isovalerate. The lower layer is a very dilute aqueous solution of isovaleric acid. Nearly all the acid formed by oxidation of the alcohol is converted at once into the ester by union with the unoxidized portion of the alcohol. Most of the uncombined isovaleric acid will be in the ester layer, since it is much more soluble in the ester than in water.

Separate the two layers with the aid of a separatory funnel. Wash the ester with a solution of sodium carbonate to remove free acid, and save the sodium carbonate solution as well as the ester. Dry the ester over anhydrous calcium chloride; then fractionally distill it. The pure ester boils at 194°.

Hydrolysis of the ester. Boil a weighed amount of the ester for twenty minutes under a reflux condenser with twice its volume of a 50 per cent solution of sodium hydroxide. Steam-distill the alkaline mixture to recover isoamyl alcohol. Saturate the distillate with sodium chloride. The alcohol separates as an oily layer on the surface of the water. Remove it from the water, dry it with anhydrous potassium carbonate, and complete the purification by fractional distillation. Isoamyl alcohol boils at 130°.

The aqueous layer from which the alcohol was removed contains the sodium salt of isovaleric acid. Add to this the sodium carbonate solution used to wash the ester. This also contains some sodium isovalerate. Make the solution neutral to litmus by the addition of dilute sulphuric acid; then evaporate it to small volume (from 75 to 100 cc.). Calculate the quantity of sulphuric acid required to liberate all the isovaleric acid from the salt (assume complete hydrolysis of the ester used). Add a 10 per cent excess of diluted (1 : 1 by volume) sulphuric acid. Shake the mixture with 50 cc. of ether. Separate the ether extract from the aqueous layer. Dry the ether extract with anhydrous calcium chloride. Distill off the ether (**Caution**) and then fractionally distill the residue of isovaleric acid. Obtain a product which boils within a range of two degrees (175°–177°).

Write a balanced equation representing the oxidation of amyl alcohol to valeric acid by chromic acid.

Write an equation for the production of amyl valerate from amyl alcohol and valeric acid.

OXALIC ACID

Oxidation of a sugar. To 100 g. of concentrated nitric acid (sp. gr. 1.40) in a liter flask add 20 g. of cane sugar. Warm the mixture on a water bath. As soon as the reaction starts (this can be seen by the evolution of nitrogen oxides), place the flask in a dish of cold water, either on the open porch or under a good hood. Allow the mixture to stand for twenty-four hours or longer. The oxalic acid crystallizes out from the concentrated nitric acid, in which it is much less soluble than it is in water. It may be separated from the acid by means of a Büchner funnel without using filter paper, or it may be filtered in an ordinary funnel through a plug of glass wool. Recrystallize the product from water by allowing a hot saturated solution to cool.

The complete oxidation of any organic compound containing carbon, hydrogen, and oxygen results in the formation of carbon dioxide and water, but the three preceding experiments are examples of partial oxidation only. Such processes depend for their success upon the fact that some intermediate, such as the formaldehyde, the valeric acid, or the oxalic acid, respectively, in the above cases, is more slowly oxidized under the specified conditions than is the original compound. The possible oxidation products may often be represented in such a series as the following:

Hydrocarbon ⟶ alcohol ⟶ aldehyde
⟶ acid ⇢ carbon dioxide.

The question as to which of the possible substances will be the main product must be solved separately for each compound and each oxidizing agent. Thus, if ethyl alcohol is oxidized by hot chromic acid, acetaldehyde is obtained in good yield, but if amyl alcohol is treated in the same way, valeric acid results. This is in part due to the fact that acetaldehyde is very volatile and escapes as fast as formed, whereas valeric aldehyde remains in contact with the oxidizing agent after being formed and is itself oxidized at a rate comparable to the rate of oxidation of the alcohol. Valeric acid, on the other hand, must be relatively slowly oxidized. Although each case under consideration must be considered separately, certain general rules apply. Thus in the above series the first step is slower than any subsequent process. As a result the oxidation of a hydrocarbon yields acids or carbon dioxide itself. Correspondingly, the rupture by oxidation of a single carbon-carbon bond is slower than that of a carbon-hydrogen bond, and the latter is relatively fast if oxygen is also present on the carbon atom in question. This conclusion is arrived at from the fact that alcohols and aldehydes are more readily oxidized than are ketones and acids. A quantitative study of oxidations and reductions is being made (1926–1927) by Conant and his coworkers, in an attempt to correlate the speed of oxidation and reduction with the strength or potential of the oxidizing or reducing agent. Much qualitative information may be obtained by a study of the published methods of preparing individual substances. Each reaction should be considered from the standpoints of its specific application and of its general availability.

ACETONE

Place 25 or 30 g. of dry calcium acetate in a large hard-glass test tube. Clamp the tube in a horizontal position, insert a one-hole stopper, and connect it, by means of a bent glass tube, to a condenser. Heat the tube with a free flame. The temperature should be raised gradually, and the heat should be uniformly distributed over the entire length of the test tube. To accomplish this, hold the burner in the hand and move the flame back and forth during the time required for the distillation. Collect the distillate in a small flask. Add about 1 g. of sodium carbonate to remove acetic acid and 4 g. of fused calcium chloride to remove water.* Allow it to stand (stoppered) until the next laboratory period. Decant the liquid into a small flask and distill it with a fractionating column. Collect the fraction distilling within a range of five degrees. Pure acetone boils at 56.5°.

To 5 cc. of a 10 per cent solution of iodine in potassium iodide add 1 cc. of acetone. Add a solution of sodium carbonate or dilute sodium hydroxide until the color due to iodine is discharged. Warm the solution to 60° on a water bath; then cool it. The yellow precipitate is iodoform (CHI_3). The test is not specific. Alcohol or acetaldehyde will produce iodoform under the same conditions.

To 1 cc. of acetone add 2 cc. of a freshly prepared saturated solution of sodium bisulphite. Describe the result. Write the equation. Filter off the precipitated crystalline addition product and dry it. Mix it with an equal weight of sodium carbonate in 10 cc. of water. Distill off 5 cc. of the liquid. Test the distillate for acetone by the method outlined in the preceding paragraph.

What is the residue in the test tube? Test a portion of it with hydrochloric acid.

Calculate the theoretical yield of acetone from the salt used. What percentage of this quantity did you actually obtain?

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* It is advisable to use only a small quantity of calcium chloride and to avoid heating the mixture. Anhydrous calcium chloride induces the aldol type of condensation in acetone.

ACETYL CHLORIDE

Place 50 g. of glacial acetic acid in a dry distilling flask provided with a dropping funnel and connected with a dry condenser. Use a small distilling flask for a receiver and make an air-tight connection between the condenser and the receiver by means of a rubber stopper. Attach a tube containing anhydrous calcium chloride to the side arm of the receiver. Place the distilling flask in a water bath containing cold water and slowly introduce 40 g. of phosphorus trichloride through the dropping funnel. Then heat the water bath to a temperature of 40°–50° and maintain this temperature until the evolution of hydrogen chloride has abated.*

Heat the water bath to boiling and collect the distillate. Purify the product by fractionally distilling it, using a free flame. Use the same precautions as before to remove the fumes. The product finally obtained may boil over a range of six degrees. The fractionating efficiency of a distilling flask is low for liquids boiling at low temperatures. A comparatively wide range (50°–56°) is allowed in this case, to avoid too great a sacrifice in the yield.

Add 1 cc. of acetyl chloride to 1 cc. of absolute alcohol, drop by drop, cooling under the tap. Then add some saturated salt solution. Describe the action. Write the equation.

Add 1 cc. of acetyl chloride to 2 cc. of aniline ($C_6H_5NH_2$). Write an equation for the reaction. The product, acetanilide, belongs to the class of compounds known as acid amides. Recrystallize it from hot water, dry it, and determine its melting point.

The reaction between acetic acid and phosphorus trichloride has sometimes been represented by the following equation:

$$3\,CH_3 \cdot COOH + 2\,PCl_3 \longrightarrow 3\,CH_3 \cdot COCl + P_2O_3 + 3\,HCl.$$

But P_2O_3 is not one of the final products obtained in this reaction, and the yield of acetyl chloride from a given amount of PCl_3 is greater than the amount calculated from the equation.

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* Unless this experiment is performed outside or in a hood, the escaping gas should be absorbed. This can be done by passing it into water through a delivery tube terminating in an inverted funnel dipping about a centimeter below the surface of the water. Another device, consisting of a T tube attached to the exit tube of the apparatus and to a water pump, is described on page 21.

The following equation also has been used:

$$3\ CH_3 \cdot COOH + PCl_3 \longrightarrow 3\ CH_3 \cdot COCl + H_3PO_3.$$

This accounts for two of the products actually obtained, but it fails to account for the formation of hydrogen chloride, which is evolved in the process. As a matter of fact the reagents present in this system are capable of reacting in many ways, and no single equation can represent all that happens. Acetyl chloride and acetic acid react to some extent, yielding acetic anhydride and hydrogen chloride. Acetyl chloride and phosphorous acid react to form a mixed anhydride, $CH_3 \cdot CO \cdot H_2PO_3$, and hydrogen chloride. The formation of these anhydrides is promoted by the ready escape of the hydrogen chloride.

The same difficulty is encountered in the preparation of an alkyl halide from an alcohol with phosphorus trihalide. Esters of the type $P(OR)_3$ are formed through the alcoholysis of phosphorus trichloride. This may, in fact, be the primary reaction, the alkyl halide being formed from the ester by a subsequent reaction between the ester and hydrogen chloride in the presence of phosphorus trichloride. Unsaturated hydrocarbons are formed from many alcohols through the action of phosphorus trichloride. This is particularly true of secondary and tertiary alcohols. The use of phosphorus trichloride in forming alkyl halides from alcohols is successful only in the treatment of the lower primary alcohols. The replacement of hydroxyl by chlorine through the agency of phosphorus pentachloride is a reaction of much wider application.

In which of the compounds $R \cdot COCl$ and $R \cdot CH_2Cl$ is chlorine more easily removed by treatment (1) with ammonia? (2) with water? (3) with alcohol?

Of the compounds $R \cdot COOH$ and $R \cdot CH_2OH$, which gives up hydroxyl more readily in treatment (1) with ammonia? (2) with alcohol?

In which of the compounds $R \cdot COOR'$ and $R \cdot CH_2OR'$ is the OR' group more readily replaced by treatment (1) with ammonia? (2) with alcohol? Notice that in each of these comparisons you are dealing with the reactivities of groups attached to $—CO—$ and $—CH_2—$ respectively.

Acetyl chloride may be prepared by many other methods. Write equations representing its production from (1) phosphorus oxychloride and sodium acetate; (2) phosphorus pentachloride and acetic acid; (3) phosgene and acetic acid; (4) oxalyl chloride and acetic acid; (5) sulphuryl chloride (SO_2Cl_2) and acetic acid.

ACETIC ANHYDRIDE

Dry about 50 g. of fused sodium acetate by heating it slowly in an evaporating dish until it begins to melt. Cool it, remove the mass from the dish, and pulverize it.

Place 40 g. of the dry powdered sodium acetate in a tubulated retort or in a distilling flask. From a dropping funnel add 25 g. of acetyl chloride. The acid chloride should be introduced slowly (one drop at a time). Interrupt the procedure occasionally and stir the mass with a glass rod to insure complete mixing of the reagents. Replace the funnel by a cork, connect the flask with a condenser, and distill the mixture. The crude distillate will contain some unchanged acetyl chloride. Transfer it to a small, dry distilling flask, add 2 g. of anhydrous sodium acetate, and redistill it. Acetic anhydride boils at 138°. Yield, 20 g.

Add a few drops of acetic anhydride to 5 cc. of water. Does it dissolve rapidly? Repeat the experiment, using a few drops of the anhydride in 5 cc. of a 10 per cent solution of sodium hydroxide. Compare the rates of solution in water and in alkali. Write equations for the reactions.

Warm a solution of 2 cc. of ethyl alcohol in 1 cc. of acetic anhydride; then allow the mixture to stand half an hour or more. Dilute the mixture with 5 cc. of water and render it slightly alkaline with sodium hydroxide. Note the odor of the product formed. Identify it. Write an equation for the reaction.

Mix 2 cc. of aniline and 2 cc. of acetic anhydride. Heat the mixture on a steam bath for a few minutes; then cool it and dilute it with an equal volume of water. Crystals of acetanilide should appear within a few minutes. Collect the crystals, dry them, and determine their melting point.

Write an equation representing the formation of acetic anhydride.

Calculate the theoretical yield based on the weight of acid chloride used.

Free acids are not readily reduced, but acid anhydrides, acid chlorides, and esters are reduced to aldehydes and finally to alcohols by sodium amalgam.

Outline a different method for making an acid anhydride.

Suggest a similar method for preparing a mixed anhydride such as $CH_3 \cdot CO \cdot O \cdot CO \cdot C_2H_5$.

In another connection (p. 79) the reactivities of elements or radicals attached to methylene and carbonyl groups (—CH_2— and —CO—) were compared. On the basis of this comparison, list esters, ethers, and acid anhydrides in the order of their rates of reaction with water and with ammonia.

ETHYL ACETATE

Mix 75 cc. of absolute alcohol, 25 cc. of concentrated sulphuric acid, and 60 g. of glacial acetic acid in a half-liter flask. Insert a tightly fitting stopper and let the mixture stand at room temperature for two or three days.* Distill off the ester with the aid of a fractionating column. To remove acetic acid cool the distillate and shake it with one fifth its volume of water. While washing it with water add from time to time a few drops of a saturated solution of sodium carbonate until the water layer is alkaline to litmus. Separate the layers by means of a separatory funnel and wash the ester again, this time using an equal volume of a saturated solution of calcium chloride to remove alcohol. Separate the layers again, dry the ester with fused calcium chloride, and redistill it. The ester boils at 77°.

Optional method. Mix 50 g. of alcohol (95 per cent) with 90 g. of concentrated sulphuric acid in a half-liter distilling flask. Prepare the mixture slowly, with constant shaking and cooling. Connect the side arm with a condenser and close the neck of the flask with a one-hole stopper fitted with a dropping funnel. Heat the flask in an oil bath. The temperature of the oil should be maintained at 140°–145°. Introduce through the dropping funnel a mixture of 100 cc. of glacial acetic acid and 100 cc. of alcohol at about the same rate as ethyl acetate distills over. Purify the product as indicated above.

The reaction is reversible. A mixture of equivalent quantities of pure acetic acid and absolute ethyl alcohol reaches equilibrium when two thirds of the acid has been converted into the ester. Sulphuric acid reduces the activity of the water formed and causes a more complete conversion of the organic acid.* The process of fractional distillation is another factor in shifting the equilibrium and increasing the yield; for although alcohol and ethyl acetate boil at the same temperature, sulphuric acid causes a greater reduction in the vapor pressure of alcohol than in the vapor pressure of the ester. A strong acid catalyzes the reaction so that equilibrium is attained more rapidly than in the absence of the acid.

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* Instead of allowing the mixture to stand at room temperature for a long time, it may be fractionally distilled after boiling under a reflux condenser for an hour.

Other methods of preparing esters consist in heating the silver salt of an acid with an alkyl iodide, and in the treatment of an alcohol by an acid anhydride or an acid chloride. The latter is frequently used in the presence of pyridine or dilute sodium hydroxide.

Why should the distillate be kept cold during the treatment with sodium carbonate solution?

Carbon dioxide is evolved when the ester is washed with sodium carbonate solution. Does the escape of CO_2 increase the loss of ester by evaporation?

Outline a method for recovering free acetic acid and alcohol from the pure ester. Why does a mixture of dry hydrogen chloride, acetic acid, and alcohol yield more ethyl acetate than ethyl chloride?

Acids that decompose when heated, and cannot be distilled, may be separated by conversion to esters which may be distilled. The esters, after separation and purification, are hydrolyzed to yield the free acids.

Esters that boil at high temperatures cannot be distilled from concentrated sulphuric acid. In such cases the ester is isolated by pouring the reaction mixture on ice, separating the ester by means of a separatory funnel, and removing free acid by washing with sodium carbonate solution. Esters which are too unstable to heat with sulphuric acid are made by saturating a mixture of the alcohol and acid with dry hydrogen chloride and allowing it to stand until equilibrium is reached. The mixture is then poured onto ice and isolated in the manner described above.

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* Water may be removed by the use of a ternary boiling mixture composed of benzene, ethyl alcohol, and water (see Methods of Drying, p. 44).

ACETAMIDE

In a small flask mix slowly, and with constant stirring, 25 cc. of ethyl acetate and 50 cc. of a concentrated solution of ammonia. Shake the mixture frequently and allow it to stand until it becomes homogeneous. With vigorous shaking, the reaction is completed within two or three hours. If the laboratory is not equipped with apparatus for shaking the flask, it may be stoppered and left in the desk until the two layers coalesce. This may require three or four days.

Fractionally distill the solution. It contains acetamide, water, ammonia, a little unchanged ethyl acetate, and a small quantity of ammonium acetate. After the low-boiling components have been removed (up to 140°), transfer the molten residue to a small distilling flask provided with a side tube near the bulb of the flask. Connect the flask with a short air condenser and distill the product. A glass tube 10 mm. in diameter and 50 cm. long will serve as an air-cooled condenser for the acetamide, which boils at 222° and solidifies at 82°. Do not allow the solid product to choke the condenser. Warm the tube if necessary, to melt the crystals and thereby prevent clogging.

Determine the melting point of the product. If it does not melt sharply, recrystallize it from ethyl acetate. Protect the product from the moisture of the air, for acetamide will absorb moisture unless it is completely free from acetic acid.

Optional method. Use a heavy soft-glass tube, 10 or 15 mm. in diameter and nearly as long as the chambers of the bomb furnace. Seal one end of the tube and introduce dry solid ammonium acetate until the tube is about half full. Then draw the open end of the tube to a capillary and seal it. Directions for sealing are given on page 281.

Place the sealed tube (commonly called a bomb) in an iron tube with the capillary end near the open end of the iron case. Introduce the iron casing containing the bomb into a furnace and heat it to 200°–225° for four hours. Take at least half an hour to raise the temperature of the bomb to 200°. When cool, cover the open end of the iron tube with a cloth and remove it from the furnace. Allow the sealed glass tube to slide down so that the tip of the capillary protrudes beyond the end of the iron case. Heat the tip of the capillary with the needle flame of a blast lamp until it softens and blows out. Never attempt to open a sealed tube in any other way, for often a considerable pressure of gas is developed, and the bomb might explode if opened by breaking the capillary. Remove the tube from the iron case and with a sharp file make a deep scratch below the capillary end, and crack the end off by pressing a red-hot glass rod on the file mark. The crack can be extended around the tube by applying a hot glass rod which is kept about 2 mm. in advance of the crack. Transfer the contents of the bomb to a distilling flask connected with a short air condenser, and distill the crude product. If the acetamide solidifies in the condenser, melt it by warming with a flame. Redistill the product and collect the fraction boiling within three or four degrees of the true boiling point. Take the melting point of the product, and if it is not sufficiently pure, recrystallize it.

Test the solubility of acetamide in various solvents, such as water, alcohol, ether, and benzene. Observe the odor of the product. Pure acetamide is odorless.

Boil a little acetamide with a dilute solution of sodium hydroxide and test for the liberation of ammonia. Write the equation.

What products would be formed if acetamide were hydrolyzed with a hot aqueous solution of hydrochloric acid or sulphuric acid? What is formed when acetamide is heated with a powerful dehydrating agent, such as P_2O_5? (See page 90.)

Could the reaction between ammonia and ethyl acetate be regarded as an ammonolysis of an ester?

What type of reaction is involved in the preparation of acetamide from ammonium acetate by heat?

Acetamide is hydrolyzed slowly by water alone at ordinary or slightly elevated temperatures. The hydrolysis is catalyzed by H^+ or OH^- ions. The reverse process (namely, the formation of acetamide from ammonium acetate) takes place only at a comparatively high temperature and in the absence of water. In the equilibrium

$$CH_3COONH_4 \rightleftarrows CH_3CONH_2 + H_2O$$

ammonium acetate is the more stable system at ordinary temperatures. Acetamide and water is the stable system only at elevated temperatures (200°). Nevertheless, acetamide is formed from ethyl acetate and ammonia in aqueous solution at room temperature.

The hydrolysis of ethyl acetate in the presence of ammonia yields ammonium acetate:

$$CH_3COOC_2H_5 + H_2O \longrightarrow CH_3COOH + C_2H_5OH,$$
$$CH_3COOH + NH_3 \longrightarrow CH_3COONH_4.$$

The ammonolysis of ethyl acetate yields acetamide, and the amide in the presence of water yields ammonium acetate:

$$CH_3COOC_2H_5 + NH_3 \longrightarrow CH_3CONH_2 + C_2H_5OH,$$
$$CH_3CONH_2 + H_2O \longrightarrow CH_3COONH_4.$$

Obviously the success of the first method described above depends upon the fact that ammonolysis of the ester is more rapid than its hydrolysis and that hydrolysis of acetamide at room temperature is slow. If the mixture were allowed to stand several weeks instead of three or four days, the principal product would be ammonium acetate. The same relations hold for many other esters of the saturated aliphatic acids.

In many cases acid amides are best prepared by the action of an acid chloride or an acid anhydride upon ammonia or an amine (see Urea and Acetanilide).

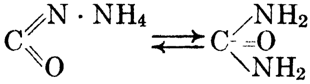
UREA

Urea can be made from phosgene by treatment with ammonia. This is the usual conversion of an acid chloride to an amide. Phosgene is a very poisonous gas and must be handled with great care.

Put 25 cc. of concentrated ammonium hydroxide solution in a small flask. In a graduated cylinder measure out 15 cc. of a 20 per cent solution of phosgene in toluene. Add the phosgene solution to the ammonia in 3-cubic-centimeter portions. Shake and cool the solution after each addition. Keep the reagents under a hood with a fan operating to produce a good draft.

Test the solution with litmus. If it is not alkaline in reaction add more ammonia. Transfer the mixture to an evaporating dish and evaporate the solution to dryness on a water bath. Extract the residue with two 15-cubic-centimeter portions of alcohol to separate the urea from ammonium chloride. Combine the alcohol extracts and filter if a residue appears upon cooling. Evaporate the filtrate to dryness. Recrystallize the product from amyl alcohol. Determine the melting point of the product. Pure urea melts at 132°.

Urea is an amide of carbonic acid. It can be made by oxidizing potassium cyanide to the isocyanate by means of a cold alkaline permanganate solution. An ammonium salt is then added, and the alkaline solution is evaporated to dryness. Ammonium isocyanate is converted into urea during evaporation. The process is reversible; but when equilibrium is attained, nearly all the product is in the form of urea.


Ammonium isocyanate Urea

Urea is sufficiently basic to form salts by the addition of acids. Only one of the amido groups is involved in salt formation. The nitrate and the oxalate of urea are easily obtained on account of their slight solubilities in acid solutions.

Urea, like other amides, may be hydrolyzed by boiling with acids or with alkalies.

Add concentrated nitric acid to a saturated solution of urea in water. Is there evidence of a reaction?

Add a saturated aqueous solution of oxalic acid to a saturated solution of urea in water.

Treat an aqueous solution of urea with sodium nitrite and a little hydrochloric acid. What is the source of the free nitrogen?

Treat an aqueous solution of urea with sodium hypobromite (bromine in an aqueous solution of sodium hydroxide). Write an equation for the reaction.

What is formed when urea is boiled with a solution of sodium hydroxide?

Gently heat some urea in a dry test tube until it melts and gives off bubbles of gas. Note the odor of the gas. Keep the liquid at this temperature for a few minutes. Cool it and dissolve the residue in water. Add a few drops of a copper sulphate solution; then add, drop by drop, a dilute solution of sodium hydroxide until the solution is clear. A violet coloration is produced. The color is due to the formation of a copper derivative of biuret. Write an equation for the formation of biuret.

HYDROLYSIS OF AN ESTER

Ethyl acetate. In a 200-cubic-centimeter flask add 20 cc. of ethyl acetate to 100 cc. of a 10 per cent solution of sodium hydroxide. Boil the mixture under a water-cooled reflux condenser until the odor of the ester disappears. This should require about twenty minutes. Distill off one third of the mixture. Collect the distillate in a very small flask and redistill it, using a fractionating column. Retain the portion that distills below 90°. To this distillate add as much dry potassium carbonate as will dissolve. Alcohol will appear as a separate layer on the surface of the aqueous solution of the carbonate. With the aid of a pipette transfer the upper layer to a test tube. From the reaction mixture a low-boiling liquid which can be salted out of an aqueous solution has been obtained. Definite identification would require complete purification and the determination of some physical constant (boiling point, density, or index of refraction). Ethyl alcohol is readily converted into iodoform by treatment with an alkaline solution of iodine, and the following test should be applied:

To 1 cc. of the distillate add an equal volume of a half-saturated solution of sodium carbonate and 20 cc. of a 10 per cent solution of iodine in potassium iodide. Warm the solution to 75° on a water bath. Keep the solution warm half an hour. If the color of iodine persists, add more sodium carbonate. A yellow precipitate of iodoform (m. p. 119°) should form.

Write an equation for the hydrolysis of ethyl acetate.

Devise a means of isolating and identifying the acid produced in this reaction (see page 162).

Write an equation representing the formation of iodoform from alcohol (see page 70).

Ethyl benzoate. Hydrolyze 5 cc. of ethyl benzoate by boiling it with 50 cc. of a normal solution of an alkali. If after half an hour the odor indicates that the ester has not been entirely hydrolyzed, add a volume of alcohol equal to one tenth of the volume of the reaction mixture and continue the refluxing until the hydrolysis is complete. From the solution obtain benzoic acid as follows: Evaporate the alkaline solution to a small volume (to about four times the volume of ethyl benzoate used). If turbid, filter the hot solution. Acidify it with sulphuric acid and allow it to cool. Benzoic acid should crystallize from the solution. Purify the product by recrystallizing it from hot water or by distilling it with steam. Determine its melting point.

A fat. Place 20 g. of fat (lard, cottonseed oil, suet, or butter) in 100 cc. of a 20 per cent solution of potassium hydroxide in alcohol. Boil the mixture under a reflux condenser half an hour; then transfer the mixture to an evaporating dish and heat it on a steam bath fifteen minutes to remove the alcohol by evaporation. On cooling, the product will set into a jellylike mixture of soap, water, glycerol, and alkali.

Melt the mass and pour it slowly into an equal volume of a hot saturated solution of sodium chloride. Allow it to cool. The solid cake that forms is a soap. Remove it from the mother liquor and suspend part of it in a small amount of hot water. Acidify the mass. Does the residue dissolve? Allow it to cool. Does a solid phase appear? Is it identical with the soap? Compare the melting points of the free fatty acids with the melting points of their salts (soaps). Write balanced equations for all reactions that have taken place.

METHYLAMINE

The Hofmann rearrangement. To a mixture of 14 g. of acetamide and 40 g. of bromine add a solution of 16 g. of sodium hydroxide in 200 cc. of water until the color becomes yellow. Then slowly add this reaction mixture to a solution of 32 g. of sodium hydroxide in 150 cc. of water; heat it to 70° until the solution becomes colorless. Distill it with steam, using a long, well-cooled condenser, and collect the distillate in 100 cc. of

6 *N* hydrochloric acid. The condenser should be fitted with an adapter dipping 1 cm. below the surface of the acid. The distillation is finished when the liquid in the condenser is neutral or only faintly alkaline. Evaporate the solution of methylamine hydrochloride to dryness on a steam bath. Extract the residue with two 50-cubic-centimeter portions of hot absolute alcohol, and filter. Evaporate off the alcohol on a steam bath until crystals begin to appear. Cool the mixture with ice water and remove the remaining solvent by means of a suction filter.

Test the solubility of methylamine hydrochloride and ammonium chloride in absolute alcohol.

Heat a little methylamine hydrochloride in a test tube with sodium hydroxide solution. Notice the odor of the gas formed. Write an equation for the reaction. Test the gas by holding a moist piece of red litmus paper over the mouth of the test tube. Repeat the test, using aniline hydrochloride instead of methylamine hydrochloride. Under what circumstances can you use this procedure to test for an amine?

Warm a little methylamine hydrochloride dissolved in alcoholic sodium hydroxide with a few drops of chloroform and notice the odor. Write an equation for this reaction. (See Chloroform, p. 67.)

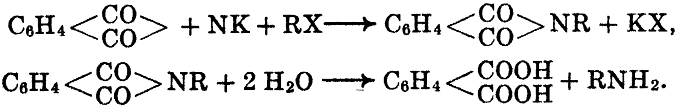
To what inorganic substance is methylamine related?

What would happen if methylamine hydrochloride were treated with sodium nitrite in acid solution (HNO_2)? Try the experiment. Repeat the experiment, using the same amounts of all reagents, but omit the methylamine hydrochloride. Did your first experiment demonstrate the reaction expected? How do you account for the evolution of gas in the absence of the amine? Is the gas nitrogen?

To distinguish nitrogen from nitric oxide and nitrogen peroxide an alkaline solution of potassium permanganate may be used (see page 218).

On a watch glass add a drop of platinic chloride solution to a drop of a concentrated solution of methylamine hydrochloride. The precipitate is a substituted ammonium salt of chloroplatinic acid.

Gabriel's synthesis represents one of the best methods for making primary amines. The reactions involve a condensation between potassium phthalimide and an alkyl halide, with subsequent hydrolysis:



$$C_6H_4\left<\begin{matrix}CO\\CO\end{matrix}\right> + NK + RX \longrightarrow C_6H_4\left<\begin{matrix}CO\\CO\end{matrix}\right>NR + KX,$$

$$C_6H_4\left<\begin{matrix}CO\\CO\end{matrix}\right>NR + 2\,H_2O \longrightarrow C_6H_4\left<\begin{matrix}COOH\\COOH\end{matrix}\right. + RNH_2.$$

ACETONITRILE

Place 10 g. of dry acetamide and 18 g. of phosphorus pentoxide in a 300-cubic-centimeter pyrex flask. Shake or stir the reagents until they are thoroughly mixed. Connect the flask with a reflux condenser and heat it gently with a small, luminous flame. Hold the burner in the hand and keep the flame moving over the surface of the flask. Foaming occurs as the reaction proceeds. After heating for ten minutes, change the position of the condenser and distill the acetonitrile into a small flask. Wash the distillate with half its volume of water; then add enough solid sodium hydroxide to saturate the water layer. Separate the two layers with the aid of a small separatory funnel and fractionally distill the acetonitrile (the upper layer) from a small distilling bulb containing about 1 g. of phosphorus pentoxide. Acetonitrile boils at 82°.

The reaction is represented by the equation

$$CH_3CONH_2 \longrightarrow CH_3CN + H_2O.$$

Ammonium acetate is partially dehydrated by heat alone, yielding acetamide (see page 83). If heated with phosphorus pentoxide, it yields acetonitrile.

Acid amides may be regenerated from the nitriles by heating with water under pressure. The temperature required varies with the cyanide used (generally from 150° to 190°). The hydrolysis of nitriles to amides may be catalyzed by hydrogen peroxide in dilute alkali.

Nitriles are hydrolyzed to ammonium salts by boiling them with acids:

$$CH_3CN + 2\,H_2O \longrightarrow CH_3COONH_4.$$

CARBOHYDRATES

Glucose. 1. Test the solubility of glucose in alcohol, in water, and in ether. As a rule organic compounds containing a relatively high ratio of hydroxyl groups to carbon atoms are much more soluble in water than in ethers or in hydrocarbons.

2. Treat 0.2 g. of the substance with 5 cc. of water; add two or three drops of a concentrated solution of α-naphthol in

alcohol. Pour 2 cc. of concentrated sulphuric acid down the side of the tube, allowing the acid to form a layer under the sugar solution. Observe the color of the ring between the water and sulphuric acid layers. Mix the two layers by gently shaking the tube. Cool under running water and finally neutralize the solution. Note the appearance at each stage of this test.

3. Add a few drops of a solution of glucose to 5 cc. of Fehling's solution, and heat the mixture on a water bath a few minutes. Describe the result.

4. Add a few drops of a solution of glucose to 5 cc. of an ammoniacal solution of silver oxide. Allow the mixture to stand without warming for ten or fifteen minutes. Is metallic silver deposited on the walls of the test tube? If not, warm the solution gently and observe the result.*

Tollen's reagent is made by precipitating the silver oxide from a solution of silver nitrate with a little dilute sodium hydroxide, and then adding just enough dilute ammonium hydroxide to dissolve the precipitate.

5. Dissolve 1 g. of glucose in 5 cc. of water; then add a solution of 2 g. of phenylhydrazine hydrochloride and 3 g. of sodium acetate in 15 cc. of water. Heat the mixture in a test tube in boiling water for half an hour. If no precipitate forms, cool the solution and allow it to stand for another half hour. Filter out the precipitated glucosazone, wash it with methyl alcohol to remove pentose derivatives and resinous matter, and dry it. It should melt, with decomposition, near 208°.

Phenylhydrazine hydrochloride may be obtained by adding phenylhydrazine to an excess of 12 *N* hydrochloric acid. The hydrochloride precipitates. It should be filtered off and washed with a little alcohol and then with ether. Free phenylhydrazine may be used instead of the hydrochloride. In this case use 2 cc. of phenylhydrazine, 3 cc. of glacial acetic acid, and 1 g. of sodium acetate in 15 cc. of water.

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* Tollen's reagent is reduced by cold solutions of aliphatic aldehydes. The reaction with glucose is slow, for this compound (potentially an aldehyde) exists chiefly in the lactone form. A rapid reduction occurs when the solution is heated but in this condition the same result is accomplished by some compounds that are not aldehydes. For example, a hot solution of a tartrate precipitates silver from the ammoniacal solution.

Sucrose. Repeat experiments 1–5, using sucrose instead of glucose.

6. Dissolve 5 g. of cane sugar in a little water, add 1 cc. of dilute sulphuric acid, and boil it for ten minutes. Neutralize the acid with sodium hydroxide.* Repeat the experiments with Fehling's solution, silver oxide, and phenylhydrazine, using this solution in place of the untreated sugar solution. With the aid of structural formulas show why sucrose and its hydrolysis products react differently.

7. Warm 0.5 g. of cane sugar with a little concentrated nitric acid. Evaporate the mixture to dryness on a water bath and dissolve the residue in dilute ammonium hydroxide. Add a drop of a solution of calcium chloride. A white precipitate of calcium oxalate is formed. Calcium oxalate is insoluble in dilute acetic acid; this distinguishes it from almost all other calcium salts of organic acids.

Lactose. Repeat the experiments outlined for glucose, but substitute lactose for glucose.

8. Evaporate 5 g. of lactose with 30 cc. of fuming nitric acid (sp. gr. 1.40) and 70 cc. of water on a water bath until a residue of about 20 cc. is left. Dilute with 50 cc. of water and allow it to stand for half an hour. Filter and wash the precipitated mucic acid. Recrystallize the acid from boiling water. The crystals melt with decomposition at 213°. Heat 1 g. of mucic acid, 0.5 g. of ammonium carbonate, and 10 cc. of glycerine in a 100-cubic-centimeter flask. The heating should be very gentle at first, until the ammonium carbonate has been decomposed; the temperature should then be raised to 170°–180°. Pyrrol is formed when ammonium mucate is decomposed by heat. Moisten a pine splinter in concentrated hydrochloric acid and hold it in the vapors which are given off. A red coloration on the pine wood will be produced if pyrrol is being evolved.

Starch. 9. Mix 1 g. of starch with enough water to make a thin cream; then add it to 200 cc. of boiling water. Boil the solution for a few minutes; then cool it. Repeat experiments 1, 2, and 3 outlined above, using this colloidal solution of starch instead of glucose.

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* Neutralization with ammonium hydroxide is not advisable, since ammonium ion reduces the hydroxide ion concentration in Tollen's and Fehling's solutions and interferes with the tests with these reagents.

10. Dissolve 2 g. of starch in 10 cc. of cold concentrated sulphuric acid and, with constant stirring, pour the solution into 20 cc. of water. Heat the resulting solution to gentle boiling for five minutes. Cool the solution and neutralize it with sodium hydroxide. Repeat experiments 2, 3, 4, and 5, using this solution. Interpret the results.

11. Add a little iodine to some starch paste. Repeat with bromine water instead of iodine. Describe the results.

Cellulose. 12. Tear a filter paper into small pieces and immerse the pieces in 20 cc. of cold concentrated sulphuric acid. Stir with a glass rod until nearly all the paper has dissolved. Remove the undissolved portions of paper with a glass rod, place them in a little water, and add a few drops of a solution containing iodine and potassium iodide. Compare this result with the action of the same reagent on untreated cellulose.

13. Pour the sulphuric acid solution of cellulose into 40 cc. of water, with constant stirring, and boil it gently for five to ten minutes. Cool the solution and neutralize it with sodium hydroxide. Repeat experiments 2, 3, 4, and 5 with the resulting solution. Interpret the results.

14. Precipitate some copper hydroxide from copper sulphate with 3 *N* sodium hydroxide. Pour off the liquid and dissolve the precipitate in ammonium hydroxide. Dissolve some filter paper in this solution with gentle heating; then filter, allowing the filtrate to fall into a dilute solution of hydrochloric acid. Describe the result.

What is the difference between an aldose and a ketose? Give an example of each.

How does glucose differ from galactose?

How many aldohexoses are known? Are others possible according to the structure theory?

What is the formula of cane sugar? How should you explain the difference between the reactions of lactose and sucrose with Fehling's solution?

What happens when cellulose is treated with hot sulphuric acid?

AROMATIC AND ALIPHATIC HYDROCARBONS

Perform the following experiments with 2-cubic-centimeter portions of benzene and with the same amount of a low-boiling gasoline. Run the two series of experiments at the same time and compare the results.

1. Burn the sample in an evaporating dish and note the character of the flame.
2. To the sample add bromine water, drop by drop, until the yellow color of bromine persists for two minutes in the oily layer; then keep the mixture in the dark, stoppered with a cork, for half an hour. Repeat with another sample to which the same amount of bromine has been added, but allow it to stand in direct sunlight for half an hour. Account for any change that occurs.
3. Introduce 1 cc. of a 5 per cent solution of bromine in carbon tetrachloride and a few iron filings into a loosely stoppered, dry test tube containing the sample. When the color of the bromine has appreciably changed, remove the stopper and blow your breath across the mouth of the tube. White fumes indicate the presence of hydrogen bromide. Repeat the experiment, omitting the iron filings.
4. Add to the sample one drop of dilute alkaline permanganate solution.
5. Add the sample slowly, with shaking, to an equal volume of concentrated sulphuric acid, and note any evidence of reaction. Repeat, using 20 per cent fuming sulphuric acid.
6. Add the sample slowly, with shaking, to an equal volume of concentrated nitric acid. Warm to 60° for fifteen minutes, using an air-cooled reflux condenser, and pour the mixture into 10 cc. of water. Has any change occurred? Repeat, using twice the volume of a cold mixture of nitric and sulphuric acids, prepared by adding carefully 2 cc. of concentrated nitric acid to 2 cc. of concentrated sulphuric acid.

Which is the better catalyst for the bromination of aromatic hydrocarbons, sunlight or iron filings?

If you wished to brominate toluene in the side chain, should you use heat and light or iron filings as the catalyst?

Does concentrated sulphuric acid facilitate the nitration of an aromatic hydrocarbon? How may aliphatic nitro compounds be prepared?

What reagent would you use to remove the aromatic hydrocarbons from petroleum?

What reagent would you use to determine whether a hydrocarbon belongs to the aromatic or to the aliphatic type?

Are the aromatic hydrocarbons saturated or unsaturated hydrocarbons? What criteria do you use to distinguish the two classes? How do you reconcile the formal unsaturation of benzene with its nonreactivity toward the reagents ordinarily used to test for unsaturation?

BROMOBENZENE

Mix 50 g. of benzene and 120 g. (40 cc.) of bromine* in a 500-cubic-centimeter round-bottomed pyrex flask. As a catalyst use about 2 g. of coarse iron filings or a few iron tacks. Connect the flask to a water-jacketed reflux condenser. The hydrogen bromide evolved in the reaction should be conducted by means of glass-tubing connections from the top of the condenser to an absorbing apparatus. Any one of the devices described on page 21 for absorbing poisonous gases will suffice.† Assemble the apparatus before mixing the reagents. Warm the mixture for an hour on a water bath at 25°-30°. If the reaction becomes violent, remove the warm-water bath and immerse the flask in cold water for a while. When the reaction becomes less energetic, heat the water bath to 65°-70° and maintain this temperature until the evolution of hydrogen bromide has nearly ceased. Cool the flask and wash the liquid product with a dilute solution of sodium hydroxide to remove unchanged bromine. Then wash it with water to remove the last traces of alkali. Dry the product over calcium chloride, decant it into a small flask, and distill it. Collect the portion boiling between 140° and 170° and redistill it. The fraction boiling between 154° and 156° is nearly pure bromobenzene.

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* The bromine should not be poured from one vessel to the other in the laboratory. Prepare the mixture under a hood or in the open-air laboratory. Bromine vapor is very harmful to breathe, and liquid bromine on the skin causes serious burns. Dilute aqueous ammonia solution should be used immediately to minimize the effects of liquid bromine on the skin or on the clothing.

† If a bubbler type of absorber is used, the apparatus should be tested for leaks before introducing the reaction mixture. If corks are bored properly and short rubber connections are made tight, there should be no need of using wax or paraffin to stop the leakage of fumes. Bromine and the halogen acids rapidly destroy rubber. Use good cork stoppers and short rubber connections.

The residue in the distilling flask (b. p. above 170°) is principally *p*-dibromobenzene. This product sometimes appears as a crystalline mass along with the monobromobenzene as soon as the contents of the reaction flask have cooled to room temperature.

Boil for half an hour a few cubic centimeters of bromobenzene with 100 cc. of 1 *N* sodium hydroxide free from chloride or bromide ions. Use a reflux condenser. Extract the resulting mixture with ether and test the aqueous layer for bromide ion. Repeat, using an aliphatic saturated monobromide and compare results. Warm benzyl bromide with dilute sodium hydroxide and test the solution for bromide ion.

Can aniline and phenol be made from bromobenzenes by the action of aqueous solutions of ammonia and sodium hydroxide respectively?

BENZYL BROMIDE

Connect a 250-cubic-centimeter flask with an air-cooled reflux condenser. To the top of the condenser connect a device for the absorption of hydrogen bromide (see page 21). Add to the flask 50 g. of toluene and 5 cc. of bromine; place the flask in the sunlight and stir the contents occasionally by shaking the flask. When the color of the bromine has disappeared, add another 5 cc. of bromine. Repeat this operation until 20 cc. of bromine have been added. When the mixture has become nearly colorless, pour the contents of the flask onto ice and water. Wash the reaction product twice with ice-cold water, then with a dilute ice-cold solution of sodium carbonate, and finally again with ice-cold water. In all these washings the reaction product should be the lower layer. Dry the reaction product quickly with calcium chloride and fractionally distill it,* collecting the fraction which distills between 195° and 200°. Benzyl bromide boils at 198.5°.

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* Benzyl bromide is a powerful lachrymator. It hydrolyzes very rapidly into benzyl alcohol and hydrochloric acid; hence the washing and drying should be done rapidly. The substance should not be allowed to stand in contact with calcium chloride longer than necessary for drying. The distillation should be carried out in a thoroughly dry apparatus to prevent hydrolysis, and the receiver should be

What would have been formed in the above experiment if the flask had not been exposed to sunlight, but a crystal of iodine or some iron filings had been added?

Which hydrolyzes the more rapidly, benzyl bromide or bromobenzene?*

If 1 per cent of benzene (m. p. 5.5°) were added to benzyl bromide (m. p. − 4°), and the solution were immersed in a freezing mixture, what would be the composition of the first crystals formed?

Why, in the case of a very reactive high-boiling substance like benzyl bromide, does the freezing of the liquid and the separation of the crystals produce a purer product than does a fractional distillation?

NITROBENZENE

Carefully add 50 g. of fuming nitric acid (sp. gr. 1.4) to 75 g. of concentrated sulphuric acid. The nitric acid should be added in small portions, and boiling should be prevented by immersing the flask in water whenever it gets uncomfortably warm to the touch. When the two acids are mixed, cool the flask in running water to room temperature and transfer the mixture to a dropping funnel. Slowly add the mixed acids to 25 g. of benzene in an open 500-cubic-centimeter flask.† Perform this operation under the hood or on the open porch. Shake the mixture vigorously after each small addition of acid, and do not allow the temperature of the mixture to exceed 65°. Cool the flask with running water under the tap as often as necessary. The reaction should be completed by heating under a reflux condenser for an hour on a water bath kept at 60°–65°. During this time the flask should be shaken

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arranged to protect the distillate from moist air. The arrangement used to handle poisonous or inflammable liquids on distillation (p. 21) will suffice in this case. The condenser used for the distillation should not be water-jacketed. Either empty the water from an ordinary long condenser or use an air-cooled condenser.

* The relative reactivities of organic halogen compounds have been extensively studied by Conant, Kirner, and Hussey, *J. Am. Chem. Soc.*, **47**, 488 (1925). Previous work is reviewed and referred to in this article.

† If the process is reversed, that is, if benzene is added slowly to the acid mixture, each drop of benzene comes in contact with a great excess of acid, and at the same time there is a greater local heating effect. As a result the principal product obtained is dinitrobenzene.

frequently. Cool the flask and pour the contents into a separatory funnel. Draw off and discard the lower layer, which is principally sulphuric acid. The upper layer is nitrobenzene. Wash the nitrobenzene several times with water (when washing the nitrobenzene with water, the lower layer will be nitrobenzene and the upper layer water). Then wash it with a dilute solution of sodium carbonate to remove the last trace of acid, and finally with water again. Dry the nitrobenzene by warming it with solid calcium chloride until it is clear. Decant the liquid from the calcium chloride; then fractionally distill it. The crude product will contain benzene (b. p. 80.4°), nitrobenzene (b. p. 210°), and dinitrobenzene (b. p. 297°). On distillation a fraction boiling over a range of 5° should be retained. Usually this range is between 206° and 211°; but if much dinitrobenzene has been formed, it is permissible to extend the range to a temperature two or three degrees above the boiling point of nitrobenzene. Do not carry the distillation above 114°.

Heat 2 g. of nitrobenzene with a mixture of 5 g. of concentrated sulphuric acid and 3 g. of nitric acid (sp. gr. 1.4) for half an hour on a boiling-water bath. Shake the mixture frequently while heating. It is advisable to use a small flask fitted with a one-hole stopper and a long glass tube, which acts as a reflux condenser. Pour the reaction product into a beaker containing 100 cc. of cold water. (Care must always be exercised when pouring concentrated sulphuric acid into water.) Dinitrobenzene solidifies and can be filtered off, washed with water, and recrystallized from 75 per cent alcohol. Determine its melting point.

To a mixture of 5 g. of nitrobenzene, 5 g. of sodium hydroxide, 20 cc. of water, and 10 cc. of alcohol add about 15 g. of zinc dust in small portions, with constant shaking. Notice the change of color, first to a deep red as azobenzene is formed, and eventually to a colorless solution as hydrazobenzene is produced. The experiment should be done in a small flask having a one-hole stopper fitted with a glass tube drawn out to a long capillary. Decant off a few cubic centimeters of the nearly colorless solution and blow air through it; notice the restoration of the red color of azobenzene. Add to the portion remaining in the reaction flask about 100 cc. of water saturated with sulphur dioxide, and filter out the precipitate of hydrazobenzene and residue of zinc. The former may be extracted by boiling the mixture with a little alcohol, from which crystals of hydrazobenzene will deposit on cooling (m. p. 125°).

If another group is introduced into the nucleus of nitrobenzene, which position will it occupy?

Outline the rearrangement that occurs when hydrazobenzene is warmed with hydrochloric acid.

Under what conditions can phenylhydroxylamine be isolated from the products obtained in the reduction of nitrobenzene? How should the conditions be varied if aniline is the desired product?

Why cannot nitrosobenzene be isolated as a reduction product of nitrobenzene*?

ANILINE

Place 30 g. of nitrobenzene and 25 g. of water in a half-liter flask connected with a reflux condenser. Add 3 cc. of concentrated hydrochloric acid and 50 g. of iron filings. Warm and shake the mixture to start the reaction. If the reaction becomes violent, cool the flask under the tap. After it ceases to boil spontaneously, heat it under a reflux condenser until it no longer has the odor of nitrobenzene. This should require about thirty minutes, but it may be necessary to use an additional 25 g. of iron and to continue the heating for an hour or more. It is important to run the reaction to completion, for unchanged nitrobenzene will combine with aniline during the alkaline distillation process later. It is not always possible to determine by reference to the odor of the mixture whether the reduction is complete. When it is believed to be complete, steam-distill the mixture until a few drops of oil have collected in the receiver. If the oil does not dissolve completely upon the addition of a few drops of concentrated hydrochloric acid to the steam distillate, or if an odor of nitrobenzene is obvious in the distillate, continue the reduction.

When the nitrobenzene has been completely reduced, make the solution alkaline by adding 15 cc. of 12 *N* sodium hydroxide. Distill the alkaline mixture with steam. The first part of the distillate will have a turbid, or milky, appearance. Even when oily droplets no longer appear in the condenser, the steam contains aniline, and at least 100 cc. of distillate should be collected after it becomes clear. The main portion of the aniline will form a separate layer in the distillate, and this may be removed at once by mechanical separation with the aid of a separatory funnel. The water layer contains aniline in solution and also in the form of an emulsion. Saturate it with sodium chloride (25 g. of salt to 100 cc. of distillate); then extract with ether (25 cc. of ether to 100 cc. of solution). Add the ether extract to the aniline obtained by mechanical separation and dry the mixture with a few small pieces of solid potassium hydroxide.* Decant the liquid mixture from the solid residue and fractionally distill it from a small flask. Use an air condenser after the ether has boiled off. Aniline boils at 184°.

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* For a discussion of the reduction of nitrobenzene see Porter's "The Carbon Compounds" (Ginn and Company).

Optional method. Place 80 g. of mossy tin and 50 g. of nitrobenzene in a liter flask. Add 20 cc. of concentrated (12 *N*) hydrochloric acid, connect the flask with a reflux condenser, and shake the mixture. There is an immediate vigorous reaction. When this subsides, add another 20 cc. of the acid and shake the mixture as before. Continue this procedure until 200 cc. of acid have been added. Then heat the flask on a steam bath for one hour or until the mixture no longer gives a test for nitrobenzene. Dilute the contents of the flask with 100 cc. of water; then add 200 cc. of a 12 *N* solution of sodium hydroxide. The hydroxide should be introduced in small quantities with frequent shaking. Rapid neutralization would make the liquid boil and might even cause an explosion. Distill the alkaline mixture with steam as long as oily drops continue to pass into the receiver or until no appreciable precipitate is formed when a test portion is treated with bromine water. Recover the aniline as indicated above. If the distillate contains unchanged nitrobenzene, as indicated by its odor, make it distinctly acid with hydrochloric acid and extract the nitrobenzene with ether. Then make the water layer alkaline and recover the aniline from it by extraction with ether.

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* Aniline, like water, ammonia, and alcohol, reacts with anhydrous calcium chloride. It also reacts with acid dehydrating agents such as phosphorus pentoxide. Potassium carbonate could be used as a drying agent.

To a mixture of 1 cc. of aniline and 10 cc. of 2 *N* sodium hydroxide add 1 cc. of benzoyl chloride. Shake the mixture vigorously until the odor of benzoyl chloride disappears. Cool the mixture and filter it. Wash the residue on the filter with very dilute hydrochloric acid. Recrystallize the precipitate from hot water, dry it, and determine its melting point. Write an equation representing its formation.

Is a solution of aniline in water neutral to litmus?

Make a saturated solution of aniline in distilled water. Add 1 cc. of the aniline water to a solution of ferric chloride. Try the same reaction with aniline and a solution of potassium aluminum sulphate (alum). Explain the results. Suggest another means of demonstrating the basic properties of aniline.

Arrange the following substances in the order of their strengths as bases: ammonia, urea, aniline, acetamide, methylamine.

Add to a small quantity of the aniline solution a few drops of bromine water.

To another portion add a freshly prepared filtered solution of bleaching powder. Describe the results.

Write a balanced equation for the reduction of nitrobenzene by tin and hydrochloric acid.

Aniline and bromine yield the white insoluble tribromaniline. Aniline and bleaching powder yield a violet condensation product of the indophenol type ($C_6H_5{-}N{=}C_6H_4{=}NH$) (see Friedrich Raschig, "Schwefel und Stickstoffstudien," *Verlag Chemie*, Leipzig).

THIOCARBANILIDE

Boil a mixture of aniline (40 g.), carbon bisulphide (50 g.), and pyridine * (17 g.) for three hours under a reflux condenser. The hydrogen sulphide evolved should be absorbed in sodium hydroxide solution in a flask connected through a trap to the open end of the condenser. The evolution of hydrogen sulphide should cease within three hours.

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* The base, pyridine, catalyzes this reaction as it and other tertiary amines catalyze reactions of acid derivatives with amines and with alcohols. Carbon bisulphide may be regarded as the anhydride of thiocarbonic acid, and the reaction involves the formation of an acid amide.

Remove the excess pyridine and carbon bisulphide by distillation with steam. Transfer the crystalline residue to a filter and wash it with dilute hydrochloric acid to remove the last traces of pyridine and aniline. Then wash it with water until free from acid, and finally dry the crystals on an unglazed porcelain plate. Thiocarbanilide melts at 154°. A yield of approximately 40 g. should be obtained.

If the melting point is not sharp, recrystallize the product from alcohol:

$$2\,C_6H_5NH_2 + CS_2 \longrightarrow CS(NHC_6H_5)_2 + H_2S.$$

Other primary aromatic amines react with carbon bisulphide in the same way.

PHENOL

Slowly add a solution of 8.5 g. of sodium nitrite in 40 cc. of water to a mixture of 20 g. of concentrated sulphuric acid, 150 cc. of water, and 10 g. of aniline until the solution gives a blue or a brown color with starch-iodide paper. If the potassium iodide used in making the test paper contains a trace of iodate, a slight color is produced by any acid solution. Sodium nitrite must be added until a well-marked test is obtained.* Heat the solution to 50° until no more nitrogen is evolved, or allow it to stand overnight. Distill the resulting mixture with steam; saturate the distillate with salt and extract the phenol with ether. Dry the ether extract with anhydrous sodium sulphate, decant, and fractionally distill the ether layers, using the method outlined for the distillation of the ether extract of benzophenone (see page 109). Phenol† boils at 183°.

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* The end point may be detected by testing for unused aniline instead of testing for an excess of nitrous acid. For this purpose the aniline is diazotized at 0° to avoid decomposition of the diazo compound. A test portion is removed from time to time during the diazotization and treated with sodium acetate solution to reduce the hydrogen ion concentration. If unchanged aniline is present it couples with diazotized aniline to form a yellow precipitate of phenyldiazoaminobenzene.

† Phenol attacks the skin. The application of alcohol or camphor affords relief.

Test the solubility of phenol in water and in other common solvents at room temperature.

To a mixture of 1 g. of phenol and 5 cc. of water add strong aqueous sodium hydroxide solution slowly until solution is complete. Saturate the solution of sodium phenolate with carbon dioxide. Repeat the experiment, using nitrophenol instead of phenol. From the results of this experiment decide which gives the highest and which the lowest hydrogen ion concentration, — a saturated aqueous solution of phenol, one of nitrophenol, or one of carbon dioxide. What effect does the introduction of a nitro group have on the acidic nature of a phenol?

Add a drop of ferric chloride solution to a dilute solution of phenol in water. Describe the result. Repeat the experiment, using α-naphthol, resorcinol, and acetoacetic ester instead of phenol.

Add bromine water to an aqueous solution of phenol. Tribromophenol is formed. Note the great ease with which phenol brominates. Repeat the experiment, using (1) aniline, (2) nitrobenzene, and (3) acetoacetic ester instead of phenol.

Add a very small crystal of sodium nitrite and a larger crystal of phenol to 2 cc. of concentrated sulphuric acid. Heat gently for a few minutes, cool, and pour the mixture into 100 cc. of water. A red color is obtained which turns blue with alkali. These color changes are produced by many nitrous acid derivatives.

Explain why phenol liquefies when mixed with a small amount of water.

What classes of (1) aromatic and (2) aliphatic compounds react rapidly with bromine at room temperature?

NITROPHENOL

Place 60 g. of concentrated nitric acid in a liter flask; then dilute the acid by adding 145 g. of water. Introduce, slowly and with constant shaking, 35 g. of phenol. The phenol may be melted by warming on a water bath, and then added to the acid a few drops at a time. A brown color develops at once, and a heavy oil is produced. Allow the mixture to stand until the next laboratory period. Decant the supernatant liquid and wash the dark oil with water until free from acid. The product consists chiefly of *ortho*-nitrophenol and *para*-nitrophenol. Distill it with steam until the distillate is colorless. The *ortho*-nitrophenol is volatile with steam and collects as a yellow oil which crystallizes when cold. Free it from water by filtration. Redissolve it in the smallest practicable quantity of alcohol at 40° and add water, drop by drop, until a faint but permanent turbidity is produced. On standing overnight the *ortho* compound is obtained as yellow crystals (m. p. 45°; b. p. 214°; yield, 12 g.).

Obtain the *para*-nitrophenol from the residue in the distilling flask by several extractions with boiling water. Combine the several water extracts, boil with bone black, and filter hot. Make the filtrate alkaline with sodium hydroxide and evaporate to a small volume (75 cc.) on the steam bath. On cooling, the sodium salt of *para*-nitrophenol crystallizes. Pour off the mother liquor and redissolve the crystals in hot water. Acidify the solution with hydrochloric acid and cool it. Free *para*-nitrophenol separates in colorless needles. Decant the mother liquor and recrystallize the compound from hot water (m. p. 114°; yield, 6 to 8 g.).

Represent by a balanced equation the conversion of *para*-nitrophenol into its sodium salt. Is there any evidence that the reaction is reversible?

Represent by structural formulas the change in color which accompanies the neutralization of *para*-nitrophenol. Write the structural formula of a colored salt of 1, 3, 5 trinitrobenzene.

SULPHANILIC ACID

Add 30 g. of freshly distilled aniline to 100 g. of concentrated sulphuric acid in a half-liter flask. The addition should be performed carefully, the aniline being added in small portions with constant shaking. The flask should be cooled in water if it becomes very hot. Careless mixing will result in an explosion. Heat the flask on an oil bath at 180°–190° until a test portion dissolves in dilute sodium hydroxide solution without leaving an oily residue of aniline. It is useless to test it before it has been heated four hours. With constant stirring pour the reaction product into water. Filter off the precipitated sulphanilic acid and dissolve it in boiling water. To clarify the solution add animal charcoal, boil it for fifteen or twenty minutes, and filter it hot. The sulphanilic acid crystallizes out on cooling.

Test a saturated solution of sulphanilic acid in water with litmus, methyl orange, and methyl violet.

Observe the solubility of sulphanilic acid in dilute alkalies, dilute acids, and concentrated acids.

What is first formed when sulphuric acid and aniline are mixed?

Benzene sulphonic acid is a strong acid. Sulphanilic acid, although stronger than acetic acid, is a weak acid. How do you account for the difference?

BENZALDEHYDE

The sodium bisulphite addition product. Add to 5 cc. of benzaldehyde a saturated solution of sodium bisulphite until no more oily drops of benzaldehyde are visible. Filter off the crystals on a Gooch filter. Test their solubility in water and in alcohol. Suspend the crystals in water, add 10 g. of sodium carbonate in water solution, and warm the mixture gently. By means of a separatory funnel remove any water-insoluble liquid that forms, wash it once with water, dry it with fused calcium chloride, and determine its boiling point. Could this same series of reactions and a similar procedure be used to separate acetone from methyl alcohol?

Spontaneous oxidation by the air. Benzaldehyde is oxidized on exposure to the air. Leave a 1-gram sample of benzaldehyde exposed on a watch glass overnight or until crystals appear. Prove that the product of the reaction is benzoic acid.

Formation of peroxides. When oxygen gas oxidizes an organic compound, the first product is usually a peroxide. The presence of peroxides may be shown by the use of a neutral or slightly acidic potassium iodide solution. The iodide ion is oxidized to iodine, which in turn may be detected by starch solution. Prepare a dilute starch solution and add to it a few drops of dilute potassium iodide solution. Place on each of two watch glasses a few drops of this solution. Add to one a few drops of benzaldehyde and to the other a crystal of benzoic acid. Stir each mixture with a stirring rod and compare the results. This comparison is necessary because an acidic solution of iodide ion is itself slowly oxidized by oxygen. Since the previous experiment has shown the possibility of the presence of benzoic acid, it must be ascertained that the acid alone has not produced the result.

Shake 5 cc. of commercial washed ether with a few drops of the starch iodide solution. If the ether has not been freshly distilled, and has been exposed to air, a test for peroxides will be obtained.

The Cannizzaro reaction. Emulsify 20 g. of benzaldehyde in 20 cc. of sodium hydroxide solution which contains at least 50 per cent of sodium hydroxide by weight. Allow the emulsion to stand overnight; add 100 cc. of water to dissolve the solid. Extract the aqueous mixture with ether,* wash the extract once with water, dry it with anhydrous sodium sulphate, and fractionally distill the solution. Benzyl alcohol boils at 204.7° at atmospheric pressure.

Add concentrated hydrochloric acid slowly to the water layer until the precipitate which forms does not redissolve rapidly upon stirring. Filter the solution and add to the clear filtrate 10 cc. of concentrated hydrochloric acid. Collect the precipitate by suction filtration, recrystallize it, if necessary, from hot water, and prove it to be benzoic acid. Compare the yield, in mols, of the benzyl alcohol and benzoic acid, and write a balanced equation for the reaction. Aliphatic aldehydes and ketones in general, under the same conditions, undergo the aldol condensation.

The aldol condensation. This condensation of aliphatic aldehydes and of ketones may also be carried out between an aromatic aldehyde and an aliphatic aldehyde or a ketone.

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* If the ether layer is washed with sodium bisulphite solution to remove unchanged benzaldehyde, it should be washed also with sodium carbonate solution to remove traces of sulphur dioxide. Traces of alkalies or acids remaining in the ether layer catalyze the conversion of benzyl alcohol to other products, such as toluene and benzaldehyde, during the distillation.

The Cannizzaro reaction (see above) is not rapid in dilute alkali, and even in strong alkali the aldol condensation is more rapid than is the Cannizzaro reaction. Prepare a mixture of 1 cc. of acetone, 4 cc. of benzaldehyde, 20 cc. of 80 per cent alcohol, and 5 cc. of 10 per cent sodium hydroxide. Boil the mixture under an air-cooled reflux condenser for five minutes and set aside overnight to cool. The crystals of dibenzal acetone may be recrystallized from alcohol.

Tests for aldehydes. Compare benzaldehyde ($C_6H_5\overset{O}{C}-H$) in its reactions with a typical aliphatic aldehyde such as acetaldehyde ($CH_3\overset{O}{C}-H$) and with a typical ketone such as acetophenone ($CH_3\overset{O}{C}-C_6H_5$) by performing the following experiments upon each of the three substances. To make the comparisons valid, use equal molal amounts of each of the three substances in each experiment* and control the total dilution of each reagent, the temperature, and the time allowed for the reaction to take place. In each experiment decide beforehand (1) what reaction to expect and (2) what observation will indicate that the reaction has taken place.

1. Prepare about 30 cc. of Tollen's reagent and divide it into three equal portions. To one portion add 1 cc. of the benzaldehyde emulsion; to the second portion add 1 cc. of the acetophenone emulsion; to the third portion add 1 cc. of the acetaldehyde solution. Shake the three mixtures thoroughly and allow them to stand for a definite time. Compare the times required for any changes to appear.

2. Test the action of Fehling's solution upon the three substances as in experiment 1. Use about 30 cc. of Fehling's solution, divided into three portions, and 1-cubic-centimeter portions of the prepared standard mixtures. After the reaction

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* This may be done by adding to each of three 20-cubic-centimeter portions of water in small Erlenmeyer flasks approximately 1.0 g. of benzaldehyde, 1.1 g. of acetophenone, and 0.5 g. of acetaldehyde respectively. Stopper the flasks tightly and shake them vigorously to emulsify the insoluble aromatic derivatives. Equal volumes of the two emulsions and of the solution contain approximately equal molal quantities of the substances to be tested. Measure out the desired volume by means of a pipette.

mixtures have stood for five minutes at room temperature, place them together in a boiling-water bath for ten minutes more. Compare the results.

3. In a manner similar to that used in experiments 1 and 2 test the action of the three substances upon a given sample of Schiff's reagent. In each of the three tests use 1 cc. of the solution and 5 cc. of Schiff's reagent.

4. Prepare a solution of 0.75 g. of phenylhydrazine in 15 cc. of 25 per cent acetic acid. Add 5-cubic-centimeter portions of the solution to 5-cubic-centimeter portions of each of the three substances being tested. Shake each mixture vigorously and allow it to stand for five minutes. Compare the results.

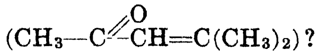
Why is it advisable, in making comparative experiments as in 1, 2, 3, and 4, to use portions of the same sample of reagent? What would be the effect upon the sensitivity of the reagent and the time required for reaction (1) of increasing the concentration of sodium hydroxide in Tollen's reagent? (2) of increasing the concentration of sulphur dioxide in Schiff's reagent? (3) of increasing the concentration of acetic acid in the phenylhydrazine solution?

What reagent would you use to test an unknown compound for the presence of the aldehyde group? for the carbonyl group?

Write a balanced equation for each reaction that has taken place in the above series of experiments. Give evidence that each reaction took place as stated.

How could you prove, by a simple series of experiments, that in the case of most aliphatic aldehydes the Cannizzaro type of reaction is much slower than is the aldol condensation?

What type of condensation of aromatic aldehydes is promoted by the cyanide ion?

How would you show (state experimental procedure) that acetone did or did not condense with itself to form mesityl oxide under the conditions of the preparation of dibenzalacetone? If it did condense with itself under those circumstances, how would you account for the formation of dibenzalacetone rather than the formation of mesityl oxide  $(CH_3-\overset{O}{\overset{\|}{C}}-CH=C(CH_3)_2)$?

What is Perkin's synthesis of unsaturated acids? Is it in any way similar to the aldol condensation? Should you expect an ester such as ethyl propionate to condense with benzaldehyde, using sodium ethylate as the catalyst?

BENZOPHENONE

The Friedel and Crafts reaction. Dissolve 20 g. of dry benzene and 20 g. of benzoyl chloride in 100 g. of dry carbon disulphide in a one-liter flask. Connect the flask with a water-cooled reflux condenser and introduce 5-gram portions of anhydrous powdered aluminum chloride* at intervals of two or three minutes until about 20 g. have been added. Heat the mixture on a water bath until the evolution of hydrogen chloride almost entirely ceases. This will require at least three hours. The upper end of the condenser must be provided with a calcium chloride tube, and this in turn should be connected to a delivery tube leading to an inverted funnel which dips just below the surface of water in a beaker on the desk. (For other devices for absorbing hydrogen chloride see page 21.)

Distill off the carbon disulphide through a long condenser. Observe the precautions given on page 21 for the distillation of inflammable liquids. Pour the residue into another flask containing 200 cc. of water and from 50 to 100 g. of cracked ice. Acidify the mixture with hydrochloric acid and distill with steam to remove the remaining carbon disulphide and unused benzene. Extract the benzophenone from the residue in the flask by shaking the mixture with ether. Dry the ether layer with calcium chloride and transfer it to a dropping funnel. Insert the dropping funnel into the neck of a small distilling flask which is connected to a long water-cooled condenser. Heat the flask on a steam bath and allow the ether extract to run from the funnel at about the same rate that the ether distills off. Finally, remove the condenser and replace the dropping funnel with a thermometer extending far enough through the stopper to bring the mercury bulb opposite the side arm of the flask. Fractionally distill the benzophenone into a large test tube. The side arm of the flask will serve as a condenser. Collect the fraction that boils above 290°. Benzophenone melts at 48° and boils at 305.9°.

Dissolve 0.2 g. of benzophenone and an equal amount of hydroxylamine hydrochloride in 5 cc. of alcohol. Render the solution alkaline with 1 cc. of a 50 per cent solution of sodium hydroxide. Warm the mixture on the water bath for an hour. Dilute the solution with 10 cc. of water, acidify it with dilute sulphuric acid, and allow it to stand until the next laboratory period. Describe the product. Write the equation. How could you convert the oxime into benzanilide?

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* See footnote under Acetophenone, p. 110.

Dissolve 2 cc. of phenylhydrazine in 6 cc. of 30 per cent acetic acid. Add 1 g. of benzophenone. Warm and shake the mixture. After cooling, filter out the benzophenonephenylhydrazone and recrystallize it from hot alcohol. The hydrazone should melt at 105°.

Outline methods for preparing diphenylmethane (1) from benzophenone; (2) by a direct Friedel and Crafts reaction; (3) by means of Fittig's reaction.

How could you use benzophenone as an intermediate in the preparation of triphenyl carbinol?

How could you prepare benzophenone from benzoic acid?

ACETOPHENONE

The Friedel and Crafts reaction. In a dry 500-cubic-centimeter flask mix 25 g. of benzene with an equal quantity of acetyl chloride. Add 50 cc. of carbon bisulphide in excess of the quantity required to produce a clear homogeneous solution, and finally introduce 25 g. of anhydrous aluminum chloride.* Immediately connect the flask with a water-cooled reflux condenser. Use a glass delivery tube with short rubber connections to convey hydrogen chloride fumes from the top of the condenser to an absorption chamber (see page 21 for methods of disposing of such a gas). The reaction proceeds essentially according to the equation

$$CH_3—COCl + C_6H_6 \longrightarrow CH_3—CO—C_6H_5 + HCl.$$

If the reaction is violent, cool the flask with water. If it becomes sluggish, warm it on a water bath. When no more hydrogen chloride is evolved, decompose the aluminum chloride by pouring the contents of the flask very slowly, and with constant stirring, into an equal volume of crushed ice. Keep it away from flames. Distill the carbon bisulphide (**Caution,** see page 21) and unused benzene from the mixture by heating it on a steam bath. Extract the ketone from the solution by shaking it with one half its volume of ether. Wash the ether extract, first with a solution of sodium carbonate and then with water. Dry it with calcium chloride. Distill off the ether by dropping the solution from a separatory funnel into a small distilling flask on a steam bath. Introduce the solution at about the same rate that ether distills over. Finally, replace the funnel with a thermometer and obtain the acetophenone by fractional distillation. Acetophenone melts at 20.5° and boils at 202°.

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* Test the quality of the available aluminum chloride before using it in this experiment. It should fume in moist air and make a hissing sound when water is dropped upon it, and a small sample of it heated gently in a test tube should sublime, leaving little or no residue.

BENZOPHENONE OXIME

The Beckmann rearrangement. Dissolve 5 g. of benzophenone and 6 g. of hydroxylamine hydrochloride in 100 cc. of 75 per cent alcohol. Add 20 cc. of a 50 per cent solution of sodium hydroxide and boil the mixture under a reflux condenser at least one hour. Dilute the product with twice its volume of water, and filter it if there is a solid or oily residue of unchanged ketone. Acidify the filtrate with dilute sulphuric acid and allow it to stand overnight. Filter out the crystalline precipitate of benzophenone oxime, wash it with water, and dry it in an air bath (m. p. 141°). In a small flask dissolve 4 g. of the anhydrous oxime in 50 cc. of absolute ether (dried by sodium). Saturate the ether solution with dry hydrogen chloride gas.* Benzophenone oxime hydrochloride precipitates as a colorless crystalline mass. Pour off as much as possible of the ether and remove the remaining portion by distillation with the aid of a vacuum pump, or evaporate it rapidly in a drying oven that is free from moisture. Without removing the salt from the flask heat it gently over a free flame until it melts. In melting, it gives off hydrogen chloride and usually acquires a brown color. At the same time the molecular rearrangement occurs. Keep the mass hot enough to prevent crystallization for five or ten minutes. Allow the product to cool and solidify. Dissolve it in 50 cc. of 95 per cent alcohol, and decolorize the solution by boiling it with animal charcoal. Filter it hot and add to the filtrate 50 cc. of hot water. Benzanilide appears in crystalline form on cooling. Recrystallize the product from 50 per cent alcohol if necessary. Pure benzanilide melts at 161°.

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* *Optional method.* Add to the ether solution, in small quantities, 5 g. of dry powdered phosphorus pentachloride. Finally, distill off the ether and treat the residue with ice water. Grind the insoluble mass under water in a mortar; then transfer it to a filter and wash it with water. Recrystallize the product from hot alcohol.

Write equations for the reactions involved in this experiment.

If phenyltolyl ketone had been used instead of benzophenone, two different oximes would have been formed. Explain. What products would they yield if treated with PCl_5?

Is there evidence that benzophenone oxime is amphoteric? Does it dissolve in alkali? Does it form salts with acids?

CINNAMIC ACID

The Perkin synthesis. A mixture of acetic anhydride * (30 g.), fused sodium acetate † (10 g.), and freshly distilled benzaldehyde (20 g.) is placed in a small flask and immersed for eight hours in an oil bath which is heated to 180°. The flask should be connected with a reflux condenser while the mixture is being heated. The upper end of the condenser should be closed with a calcium chloride tube.

Pour the hot mixture into a 500-cubic-centimeter distilling flask, add 200 cc. of water, and remove all unchanged benzaldehyde by distillation with steam. Filter the hot solution, leaving as much as possible of the solid residue in the flask. Extract the residue with additional hot water and filter it. Continue this practice until an extract is obtained which, when cooled, yields no crystals of cinnamic acid. Combine all the filtrates and decolorize the solution by boiling it with animal charcoal. Filter the solution and set it aside to cool. Cinnamic acid should crystallize out. Dry the crystals and determine their melting point. Pure cinnamic acid melts at 133°. Yield, 15 g.

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* The acetic anhydride should be fractionally distilled before using, to free it from acetic acid.

† For the preparation of dry sodium acetate see page 80.

Write the formula of the product that would be formed by the action of benzaldehyde on a mixture of sodium propionate and propionic anhydride.

To a hot aqueous solution of cinnamic acid add a few drops of bromine water. Describe the result. Write an equation for the reaction. Should you expect an alkaline solution of the salt of cinnamic acid to decolorize potassium permanganate? Try it.

What methods are generally used for the preparation of purely aliphatic unsaturated acids?

NOTE. The method corresponding to this preparation — by substituting an aliphatic aldehyde for benzaldehyde — cannot be used, since aliphatic aldehydes containing a hydrogen atom on the α-carbon atom readily undergo the aldol condensation under the influence of dehydrating agents.

HYDROCINNAMIC ACID

Reduction of an unsaturated acid. Place 5 g. of cinnamic acid in a small flask with 60 cc. of water. Add enough 2 *N* sodium hydroxide solution to dissolve the acid. Then introduce 100 g. of $2\frac{1}{2}$ per cent sodium amalgam (see page 303) in 10-gram portions, allowing each portion to react ten or fifteen minutes before adding more. Shake the mixture frequently.

Allow the mixture to stand until the next laboratory period. Then decant the clear aqueous solution and acidify it with hydrochloric acid. Hydrocinnamic acid precipitates as an oil and solidifies on standing. Recrystallize the product from warm water. Hydrocinnamic acid crystallizes in the form of long, colorless needles melting at 47°.

The mercury liberated from the amalgam should be washed with water and returned to the storeroom.

What is the function of the mercury in sodium amalgam?

Suggest other agents that might be used to reduce cinnamic acid to hydrocinnamic acid.

Hydrocinnamic acid is volatile with steam. Make use of this property, if necessary, in purifying the product.

Under what conditions is hydrogen gas used in reducing organic compounds?

DIPHENYLETHYL CARBINOL

The Grignard reaction. Suspend 2.4 g. of clean, dry magnesium turnings in 50 cc. of anhydrous ethyl ether* in a 200-cubic-centimeter flask. Add a small crystal of iodine (a catalyst) and 15.6 g. of pure, dry ethyl iodide or 11 g. of ethyl bromide. Connect the flask with a water-cooled vertical reflux condenser protected from moisture by a calcium chloride tube at the top. Ice and water should be available to cool the flask if boiling becomes so rapid as to cause incomplete condensation in the condenser. It is sometimes necessary to warm the mixture in order to start the reaction. When it no longer boils spontaneously, warm the flask on a water bath or over an electric hot plate to keep the ether boiling gently until the magnesium has dissolved. An hour or more may be required to complete the reaction. The Grignard reagent, C_2H_5MgI, is soluble in ether. If it precipitates, add a little more ether. If, after boiling for an hour, a residue of undissolved magnesium remains in the flask, decant the ether solution into another dry flask before proceeding to the next step.

Dissolve 18 g. of benzophenone in 100 cc. of dry ether and pour the solution slowly through the condenser into the ether solution of the Grignard reagent. When the reaction has apparently ceased, warm the mixture on a water bath and keep the ether boiling for an hour or more.

After cooling pour the contents of the flask slowly into a beaker containing cracked ice and 50 cc. of normal hydrochloric acid.

Stir the mass vigorously as the mixture goes onto the ice, in order to avoid local heating. If magnesium hydroxide precipitates and does not redissolve on stirring, add a little more acid.

Transfer the solutions to a separatory funnel and separate the aqueous and ether layers. Dry the ether layer with solid anhydrous sodium sulphate. Decant it from the solid residue and distill off the ether. Recrystallize the product from alcohol and determine its melting point. The pure substance melts at 94°–95°.

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* Commercial ether must be dried by means of sodium (see page 71). Use a sodium press to obtain the metal in the form of a wire. In this form a large surface is exposed. Leave the ether in contact with sodium as long as hydrogen is evolved; then distill it from a water bath. Be careful to dispose of all sodium residues. A safe procedure is to dissolve the unused sodium in alcohol and then dilute the solution with water before pouring it into the sink.

Write an equation for each reaction involved in this preparation.

Devise a means for making the same product from ethylphenyl ketone ($C_2H_5 \cdot CO \cdot C_6H_5$).

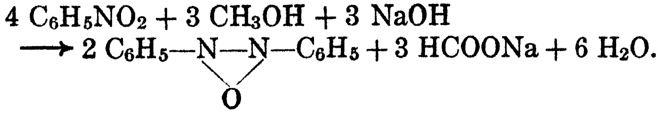
Name several classes of compounds that react with the Grignard reagent, and name the class of compound produced as a result of each reaction.

What would happen if the Grignard reagent were treated with water? with alcohol? with acetic acid?

AZOXYBENZENE

Methyl alcohol may be used as a reducing agent in the preparation of azoxybenzene from nitrobenzene. Commercial methyl alcohol usually contains some acetic acid and acetone. It is purified in the following manner: Add to 300 cc. of the alcohol, in a distilling flask, several grams of anhydrous sodium carbonate. Distill it, using a fractionating column. The first 50 cc. that distills over will contain most of the acetone, and this portion is saved for the later recrystallization of the azoxybenzene. The next 200 cc. that distills over may be used in the preparation. The residue in the flask is discarded.

To 200 cc. of purified methyl alcohol add 45 g. of powdered sodium hydroxide and then 30 g. of nitrobenzene. The mixture is boiled on a water bath under a reflux condenser for three hours. The greater part of the alcohol is then distilled off, the distillate being saved for use in recrystallization later. The residue is poured into cold water, and the precipitated yellow oil is frozen with ice and washed several times with water. If the oil does not solidify under the cold water, it contains unreduced nitrobenzene or aniline, either of which can be removed by steam distillation. It is recrystallized from methyl alcohol. Azoxybenzene melts at 36°.



$$4\,C_6H_5NO_2 + 3\,CH_3OH + 3\,NaOH \longrightarrow 2\,C_6H_5{-}\underset{\underset{O}{\diagdown\diagup}}{N{-}N}{-}C_6H_5 + 3\,HCOONa + 6\,H_2O.$$

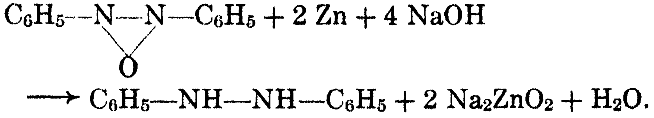
The formation of azoxybenzene involves several independent steps, the last of which is the condensation of nitrosobenzene and phenylhydroxylamine in the presence of alkali. Represent the various steps in the form of balanced equations.

AZOBENZENE

Mix 5 g. of dry, powdered azoxybenzene with 15 g. of coarse, dry iron filings. Grind them together in a mortar. Place the mixture in a small retort and warm it gently with a free flame. Gradually increase the temperature until azobenzene distills over. Slight explosions will interfere with the success of the experiment if the mixture is not dry. Wash the red distillate with hydrochloric acid to remove aniline. Wash out the acid with water; then filter and dry the product. It can be crystallized from ligroin by allowing the solvent to evaporate at room temperature. Azobenzene melts at 68°.

HYDRAZOBENZENE

Dissolve 12 g. of recrystallized azoxybenzene in 200 cc. of alcohol in a pyrex flask which is equipped with a reflux condenser and connected to a mercury or water trap to prevent free access of air to the flask. Add 8 g. of sodium hydroxide in 12 cc. of water, and then 15 g. of zinc dust. Heat the mixture on a water bath with frequent shaking until the solution becomes colorless or pale yellow. If necessary, more zinc dust may be added, care being taken to cool the solution so that the addition of the zinc dust will not cause violent boiling. The hot solution is filtered by suction through a Büchner funnel from the excess of zinc. The filtrate is allowed to fall into 100 cc. of water to which has been added 20 cc. of water saturated with sulphur dioxide. Hydrazobenzene precipitates in the filter flask. It is filtered quickly, washed with water containing sulphur dioxide, and dried on a porous plate. Hydrazobenzene melts at 126°.



$$C_6H_5\text{—}\underset{\diagdown\, O \,\diagup}{N\text{—}N}\text{—}C_6H_5 + 2\,Zn + 4\,NaOH$$

$$\longrightarrow C_6H_5\text{—}NH\text{—}NH\text{—}C_6H_5 + 2\,Na_2ZnO_2 + H_2O.$$

Dissolve a few crystals of hydrazobenzene in 30 per cent alcohol containing a little sodium hydroxide and shake the solution with air. Account for the appearance of a red color.

BENZIDINE

Shake 1 g. of hydrazobenzene with 5 cc. of concentrated hydrochloric acid for five minutes. Dilute the solution and make it alkaline by the addition of sodium hydroxide. Extract the solution with two or three small portions of ether. Dry the ether extract and evaporate off the ether. Recrystallize the product from hot water. Benzidine melts at 128°.

How would you determine that the substance isolated in the above experiment is not unchanged hydrazobenzene?

Give another example of this type of rearrangement.

What common salt of benzidine is very sparingly soluble in water?

HELIANTHIN

Dissolve 10 g. of sulphanilic acid in 125 cc. of a 3 per cent solution of sodium carbonate. Cool the mixture to 5° or below by surrounding the beaker with ice. Add 4.2 g. of pure sodium nitrite dissolved in 25 cc. of water.* Stir the solution, and at the same time add slowly a volume of hydrochloric acid containing 2.5 g. of anhydrous hydrogen chloride.†

Pour the diazotized sulphanilic acid into a cold solution of dimethylaniline hydrochloride prepared by dissolving 7 g. of dimethylaniline in just enough 1 *N* hydrochloric acid to produce a clear solution. Finally, with constant stirring, add a 20 per cent solution of sodium hydroxide until the mixture is distinctly alkaline to litmus paper. Cool the mixture and let the precipitate coagulate by standing at least an hour. It is more easily separated from the liquid if the mixture is heated for a few minutes on a steam bath and then allowed to stand for several hours before filtering.

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* If the purity of the sodium nitrite is unknown, add the quantity specified above; then, after adding the hydrochloric acid, introduce more nitrite solution, a drop at a time, until a drop of the mixture produces an immediate blue color on starch-iodide paper. For the preparation of the test paper see page 302.

† If hydrochloric acid of known concentration is not available, make a mixture of concentrated acid with an equal volume of water, determine its specific gravity, and refer to Landolt and Börnstein's tables for the percentage of anhydrous acid in the solution. The concentration of hydrochloric acid may be approximately calculated by multiplying the decimal part of its specific gravity by 200. If, for example, the specific gravity is 1.125, the acid is about 25 per cent HCl; that is, 200 × 0.125 = 25.0.

Filter out the dye. Redissolve it in as little boiling water as possible, filter hot, and cool the filtrate. The dye crystallizes as the solution cools. Dry the crystals on a porous plate.

Add a solution of sodium nitrite to an ice-cold dilute solution of dimethylaniline hydrochloride containing an excess of hydrochloric acid. (The solution may be prepared by dissolving a few drops of dimethylaniline in dilute hydrochloric acid.) To the clear yellow solution add enough dilute sodium hydroxide solution to render it alkaline. Does acid redissolve the precipitate? Write an equation for the reaction. Is this a diazotization?

Write the structural formulas of helianthin and of its sodium salt. Write equations for all reactions involved in their preparation.

How would an excess of nitrous acid affect the results of this experiment?

How would insufficient nitrous acid affect the result?

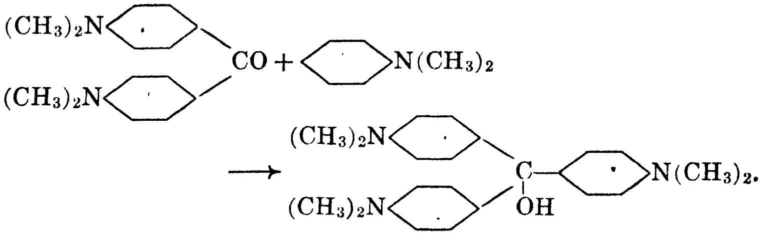
What would happen if the amine were diazotized in a warm solution?

Was the dye formed before or after adding the sodium hydroxide to the mixture of diazotized sulphanilic acid and dimethylaniline hydrochloride? Explain, basing your argument on the color of the solution at the various stages of the preparation.

CRYSTAL VIOLET

Place 20 g. of dimethylaniline with 8 g. of tetramethyldiaminobenzophenone (Michler's ketone) and 8 g. of phosphorus oxychloride in a dry liter flask. Connect the flask with a reflux condenser and heat the mixture on a water bath for five or six hours. Add 400 cc. of water and enough sodium hydroxide to render the solution alkaline. Remove any unchanged dimethylaniline by distillation with steam. Cool the alkaline mixture remaining in the distilling flask and filter it. The solid residue is the color base of crystal violet. Wash it with water; then transfer it to a clean flask or beaker. Boil the base with a small volume (100 cc.) of very dilute hydrochloric acid (5 cc. of concentrated hydrochloric acid per liter of water). Filter the hot solution. Boil the undissolved residue with more of the dilute hydrochloric acid and filter hot. Continue this procedure until substantially all the base has been converted into the dye salt and has dissolved. Saturate the combined filtrates with sodium chloride (25 g. of salt for every 100 cc. of dye solution). Stir until the salt has dissolved and filter if necessary. Allow the solution to stand until the next laboratory period. Filter out the precipitated dye, with the aid of a Büchner funnel and a filter pump, and dry it.

In the presence of phosphorus oxychloride Michler's ketone and dimethylaniline form an addition product:



Write an equation representing the action of hydrochloric acid on the color base.

Represent graphically the change from the benzoid to the quinoid form.

By what means may this change be reversed?

PHENOLPHTHALEIN

Heat a mixture of 10 g. of phthalic anhydride, 20 g. of phenol, and 8 g. of concentrated sulphuric acid in an oil bath to 115°–120° for eight hours. Pour the mixture, while hot, into a beaker containing 500 cc. of water and boil it. Replenish the water from time to time and continue to heat it until the odor of the phenol can no longer be detected. Filter out the crude phenolphthalein, dissolve it in a 5 per cent solution of sodium hydroxide, and filter to remove insoluble impurities. Neutralize the solution with acetic acid, then add to it a few drops of concentrated hydrochloric acid, and allow it to stand until the next laboratory period. Filter and dry the precipitate. Dissolve it in 50 cc. of alcohol and boil the solution with animal charcoal under a good reflux condenser for about half an hour. Filter the solution hot and boil off a third of the alcohol; then cool it and dilute it with eight times its volume of water. Filter it at once through a cloth filter. Cloth retains some of the resinous by-products. Distill the filtrate until the boiling point shows that substantially all the alcohol has been removed. On cooling, phenolphthalein precipitates. If the product is still colored, take it up in alcohol, boil it with animal charcoal, and reprecipitate as before.

Notice the color of phenolphthalein in dilute and in concentrated sulphuric acid, and in dilute and in concentrated aqueous solutions of NaOH, NH_4OH, CH_3COONa, and $NaHCO_3$.

Explain the color change produced by phenolphthalein in passing from an acid to an alkaline solution.

Why does sodium acetate behave like a base?

Which shows an alkaline reaction with the smaller concentrations of hydroxide ions: phenolphthalein or litmus?

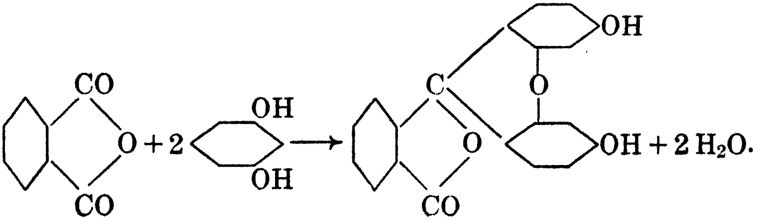
In titrating acetic acid, which should you prefer to use as an indicator: phenolphthalein or methyl orange? Why?

Name other phenols that react with phthalic anhydride to form substances similar to phenolphthalein.

Write the formulas of two triphenylmethane dyes that are not phthaleins.

FLUORESCEIN

Grind together 5 g. of phthalic anhydride and 7 g. of resorcin and heat the mixture in a porcelain, nickel, or iron dish in an oil bath at 180° until the mass melts. Add 4 g. of anhydrous zinc chloride and raise the temperature to 210°. Continue the heating at this temperature for two hours. Cool and pulverize the fused mass. Boil it for a few minutes with 75 cc. of dilute hydrochloric acid (1 : 10) and filter. Dry the residue.



Dissolve a very small quantity of fluorescein in a 10 per cent solution of sodium hydroxide. Observe the color by reflected light and by transmitted light.

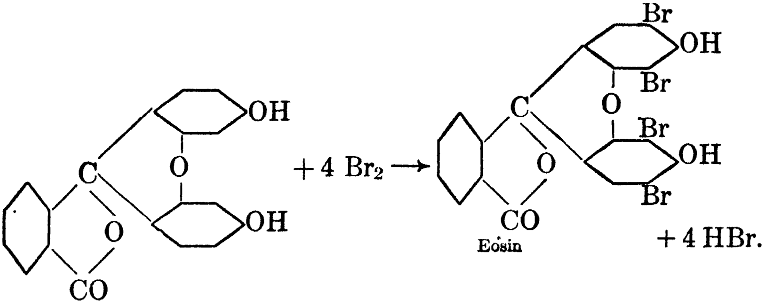
Write a structural formula for the sodium salt of fluorescein.

What is meant by *fluorescence*? by *phosphorescence*?

Explain why smoke is blue by reflected light and red by transmitted light.

EOSIN

Mix 10 g. of fluorescein with 50 cc. of 95 per cent alcohol and add 6 cc. of bromine, one drop at a time, from a burette. A clear solution should be obtained when half of the bromine has been added. The last 3 cc. of bromine should precipitate eosin. Separate the dye from the liquid by filtration, wash it with alcohol, and dry it.



Account for the fact that fluorescein reacts with bromine to give this particular tetrabromide, but fails to form a higher bromide or any other tetrabromide.

TRIPHENYLCHLOROMETHANE

In a half-liter round-bottomed flask mix 20 g. of dry carbon tetrachloride with 100 g. of benzene. Connect the flask with a reflux condenser. Place the apparatus under a hood or on the open porch. Protect the contents of the flask from moisture by attaching a calcium chloride tube to the condenser. From time to time disconnect the condenser long enough to introduce into the flask 2 or 3 g. of powdered, dry aluminum chloride.

A vigorous reaction accompanied by the evolution of hydrogen chloride results, and the rate of addition of the aluminum chloride must be regulated so that this reaction does not become violent. After 25 g. of aluminum chloride have been added, heat the mixture on a water bath for an hour to complete the reaction. Cool the flask to room temperature or below; then pour the contents slowly, and with constant stirring, into a large porcelain evaporating dish which is half full of crushed ice. Enough hydrochloric acid should be added to dissolve the aluminum hydroxide. It may be necessary also to add more benzene to keep the triphenylmethyl chloride and triphenyl carbinol in solution. To prevent the crystallization of benzene in the treatment with ice it may be necessary to add a few cubic centimeters of ether. Remove the benzene layer and dry it with calcium chloride. To the dry solution add 15 cc. of acetyl chloride.* Distill the mixture on a steam bath until the rate of distillation becomes slow. Add the residue to an equal volume of warm ligroin and allow the solution to cool. Filter out the crystals that precipitate on cooling. Wash them with ligroin and dry them in an air bath. Triphenylchloromethane melts at 112°.

QUINOLINE

Add 100 g. of concentrated sulphuric acid to a mixture of 38 g. of aniline, 24 g. of nitrobenzene, and 120 g. of glycerol in a two-liter flask fitted with a reflux condenser. Add the acid slowly, stirring the mixture constantly. Heat the flask very cautiously with a free flame until white vapors begin to rise from the liquid. If the reaction becomes violent, remove the flame. After the reaction has subsided, place the flask on a sand bath and apply heat enough to keep the contents gently boiling for about three hours. Cool the mixture, dilute it with water, and distill it with steam to remove unchanged nitrobenzene. To the residue in the distilling flask add a concentrated solution of sodium hydroxide until the mixture is strongly alkaline, and again distill with steam. This time the distillate will contain the quinoline, which, however, is contaminated with aniline. To remove the aniline add to the distillate enough dilute sulphuric acid to make the mixture distinctly acid. Introduce sodium nitrite in aqueous solution until a test portion of the mixture turns starch iodide blue — a test for free nitrous acid — or until it no longer gives the hypochlorite test for aniline. Boil the diazotized solution until no more nitrogen is evolved. To obtain the quinoline make the solution strongly alkaline by adding sodium hydroxide, and finally distill it with steam. Extract the distillate with ether. Dry the ether solution with solid sodium hydroxide. Distill off the ether and then fractionally distill the remaining quinoline.

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* Acetyl chloride is added for the purpose of converting triphenyl carbinol into triphenylchloromethane. The same result may be achieved by saturating the dry benzene solution with hydrogen chloride gas.

Treat quinoline with a mixture of platinic chloride and hydrochloric acid. Describe the result.

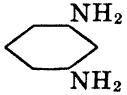
Warm an equimolal mixture of quinoline and methyl iodide; then cool the mixture. Write a structural formula for the product. Does it ionize in water?

Treat quinoline with a solution of bromine in chloroform ($C_9H_7NBr_2$ is formed).

The method outlined above is known as Skraup's synthesis.

What is the function of nitrobenzene in this reaction?

What would be formed if *meta*-phenylenediamine,



were treated with excess of glycerol and nitrobenzene in the presence of concentrated sulphuric acid? Write an equation representing the reaction.

What is isoquinoline? Outline a method for making it.

Name two alkaloids in which the quinoline nucleus appears.

Does quinoline react with dilute hydrochloric acid?

PHOTOCHEMICAL REACTIONS

Many reactions that proceed slowly in the dark or in diffused light are accelerated by exposure to direct sunlight or to the radiation of an incandescent filament or an electric arc. A few reversible photochemical processes are known, equilibrium being shifted in one direction by exposure to light and in the opposite direction in the dark. Anthracene, $C_{14}H_{10}$, is converted into dianthracene, $C_{28}H_{20}$, by exposure to light. In the dark the polymer reverts to the monomolecular form.

In the chlorination of toluene the course of the reaction can be controlled so as to introduce the halogen into the ring or into the side chain. In the presence of light and at the boiling point of toluene, substitution occurs in the side chain. In the absence of light, at lower temperatures, and in the presence of iron as a catalyst, substitution occurs in the ring.

Some photochemical processes are induced by radiation corresponding to a very limited region of the spectrum. Acetone vapor is stable in visible light but is decomposed to carbon monoxide and ethane by ultra-violet radiation of wave lengths between 3400 and 2100 Ångström units.

MONOCHLOROACETIC ACID

Prepare a mixture of 60 g. of glacial acetic acid and 5 g. of red phosphorus* in a flask fitted with a reflux condenser. Heat it on a boiling-water bath with the flask exposed to direct sunlight. Pass a slow current of chlorine† through the mixture until a test portion crystallizes when cooled to 0° and rubbed with a glass rod. The time required may be four or five hours. Fractionally distill the reaction product and collect the portion boiling between 150° and 200°. Cool to 0° and rub the sides of the vessel with a glass rod or inoculate the liquid with a crystal of monochloroacetic acid to start the process of crystallization. After a crop of crystals has formed, filter rapidly with suction. Another yield of crystals of monochloroacetic acid can be obtained from the filtrate by distilling it and crystallizing the fraction obtained between 170° and 200°. Redistill the combined yields, collecting the portion passing over between 180° and 190°.

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* The substitution of a halogen for hydrogen on the α-carbon atom of an ester or an acid chloride is accelerated by light. The α-carbon in an ester or an acid chloride is much more reactive than in an acid. Hence, to obtain an α-chloroacid the chlorination is carried out in the presence of phosphorus. The phosphorus trichloride formed converts the acid into an acid chloride, which is then chlorinated. By hydrolysis of the substituted acid chloride an α-chloroacid is produced.

† If chlorine is not available in tanks, generate it by allowing concentrated hydrochloric acid to flow, drop by drop, on powdered potassium permanganate. Use a distilling flask and warm gently if necessary. Pass the gas through two wash bottles, one containing water and the other concentrated sulphuric acid.

Warning. Monochloroacetic acid attacks the skin and must be handled with care. Chlorine is a poisonous gas. The experiment should be performed under a good hood or on the porch desks provided for open-air experiments. The gases issuing from the reflux condenser must be absorbed in a solution of sodium hydroxide.

Make 2 *N* solutions of acetic acid, monochloroacetic acid, and trichloroacetic acid, and add a few drops of methyl violet to each. Compare the colors. Explain the differences.

Boil a few crystals of monochloroacetic acid with a little dilute sodium hydroxide for a few minutes, acidify with nitric acid, and test for chloride ion. Write equations for the reactions.

Write the structural formula of the product formed when propionic acid is chlorinated.

What effect does the chlorination of an acid have on the strength of the acid?

Represent by an equation another reaction of chlorine that is catalyzed by light.

TETRAPHENYLPINACOL

Prepare a saturated solution of benzophenone in 75 per cent alcohol. Place most of the solution in a transparent quartz flask and expose it for two hours to the radiation of a quartz mercury-vapor lamp. The sample should be not more than 20 cm. from the mercury-vapor arc.* For comparison place the remaining portion of the solution in a dark glass flask or in an ordinary flask wrapped in black paper. Keep the two flasks side by side so that the only difference in the conditions will be the admission of light to one flask and the exclusion of light from the other.

In the flask exposed to ultra-violet light, tetraphenylpinacol begins to precipitate after a few minutes, and a 75 per cent yield can be expected within two hours. No change will occur in the dark flask. Obtain the crystals by filtration and dry them in an air bath. They should melt at 186°.

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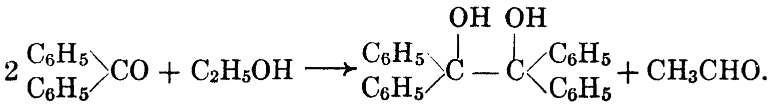
* The reduction can be carried out in pyrex if quartz is not available, but a longer exposure is required. This reduction is induced by violet as well as by ultra-violet light.



$$2\,\begin{matrix}C_6H_5\\C_6H_5\end{matrix}\!\!>\!CO + C_2H_5OH \longrightarrow \begin{matrix}C_6H_5\\C_6H_5\end{matrix}\!\!>\!\overset{\displaystyle OH}{\overset{|}{C}}-\overset{\displaystyle OH}{\overset{|}{C}}\!<\!\begin{matrix}C_6H_5\\C_6H_5\end{matrix} + CH_3CHO.$$

QUESTIONS FOR REVIEW

1. Under what circumstances would the evaporation (or distillation) of a solution of two liquids not involve a change of composition of either vapor (distillate) or liquid? Is this ever possible where the vapor-pressure-composition relation for each component corresponds to Raoult's law?

2. Why is a fractionating column more efficient than an ordinary distilling flask? In some commercial stills designed for the distillation of low-boiling liquids the upper portion of the fractionating column is artificially cooled and the lower portion is insulated. What advantage is gained by this practice?

3. Why is it not possible to obtain the boiling point of a mixture of alcohol and water by noting the distillation temperature as taken in an ordinary apparatus?

4. Would the following drying agents be suitable: calcium chloride for alcohol, calcium chloride for ammonia, sodium amalgam for ammonia, and soda lime for acetic acid?

5. Correlate the oxidation of chloroform to phosgene with the following facts: (1) alcohols are oxidized to aldehydes or ketones; (2) aldehydes and ketones do not, as a rule, add water or halogen acid to the carbonyl group.

6. Correlate the hydrolysis of chloroform to formic acid with the hydrolysis of ethyl iodide to alcohol.

7. Compare the equations given for the preparation of CHI_3 and for $CHCl_3$. Is there any justification for the use of Cl_2 in one case and NaOI in the other? Does I_2 react with hydrocarbons by substitution? The chlorination of acetone could proceed through the addition of chlorine to the enol form. Write the reactions, using structural formulas.

8. What is formed when iodoform is heated with alcoholic potash? Does chloroform react with alcoholic potash in the same way? Are alkyl chlorides hydrolyzed as rapidly as are alkyl iodides?

9. Ethers and esters are sparingly soluble in water and in dilute aqueous acids but very soluble in cold concentrated sulphuric acid. Devise a simple experiment to prove that when an ether dissolves in cold concentrated sulphuric acid it is not hydrolyzed to alcohol, and that it does not react according to the equation

$$R_2O + 2\ H_2SO_4 \longrightarrow 2\ RHSO_4 + H_2O.$$

10. Using concentrated sulphuric acid as a reagent, how could you distinguish between a saturated hydrocarbon and a saturated ether?

11. Which of the following anhydrides is the most readily hydrolyzed: an acetal, an acid anhydride, an ether, or an ester? Which is the least readily hydrolyzed? Does the term *readily* refer to the completeness of the reaction or to the rate of the reaction? In each case is the reaction rate catalyzed more by acid or by alkali?

12. Devise an experiment to prove that the formation of hexamethylenetetramine (urotropine) from formaldehyde and ammonia is a reversible reaction.

13. Is the addition of sodium bisulphite to an aldehyde a reversible reaction? What is the solid precipitate formed when ethyl alcohol is added in equal volume to a concentrated solution of sodium bisulphite?

14. Devise an experiment to prove that the addition of sodium hydroxide to an ammoniacal silver solution hastens the reduction of the silver ion by an aldehyde, and that too high a concentration of sodium hydroxide will cause the silver solution to be rapidly reduced by alcohol as well as by an aldehyde.

15. Explain why the product of the reaction between metallic sodium and ethyl alcohol rapidly becomes discolored in the air, whereas the corresponding product with methyl alcohol does not.

16. When ethyl alcohol is oxidized by chromic acid by adding an alcohol and sulphuric acid mixture slowly to a hot solution of sodium dichromate, acetaldehyde is the chief product. Compare the procedure and result with that of the preparation of valeric acid from amyl alcohol. Explain why the one alcohol yields an aldehyde, whereas the other yields an acid.

17. Arrange the following reactions in the order of their specific reaction rates: (1) oxidation of amyl alcohol to valeric aldehyde by chromic acid; (2) oxidation of valeric aldehyde to valeric acid by

chromic acid; (3) esterification of amyl alcohol by valeric acid in the presence of sulphuric acid; (4) oxidation of amyl valerate to valeric acid by chromic acid.

NOTE. The experiment outlined on page 74 does not afford sufficient evidence for the solution of this problem. Use the available evidence and estimate the relative rates of those reactions for which there are no good data.

18. Could you hope to prepare valeric aldehyde by the oxidation of amyl alcohol by using some other oxidizing agent than chromic acid? Explain.

19. The preparation of ethyl acetate sometimes results in a crude product boiling at 70°–72°, whereas the desired product boils at 77°. What is the cause of this difficulty? How may the pure ester be obtained from the crude material?

20. Give examples of carbon-carbon bonds that are broken by hydrolysis when heated with an acid or an alkali. Give examples of carbon-oxygen bonds that are broken in the same way.

21. Give the name of one class of compounds containing nitrogen whose carbon-nitrogen bond is readily broken by hydrolysis. Illustrate by a balanced equation.

22. If one mol of butyryl chloride (C_3H_7COCl) is treated with one mol of ammonia and one mol of sodium hydroxide simultaneously, in dilute aqueous solution, almost one mol of butyric amide is formed. Which reacts the fastest with the acid chloride: the hydroxide ion, water, or ammonia?

23. Write a balanced equation for the reaction (1) between bromine and hydroxide ion; (2) between bromine and water; (3) between bromine and ammonia; (4) between bromine and acetamide. All these reactions are reversed by the addition of acid. Write the reverse reactions.

24. By indirect methods water can be introduced into an ethylene, a saturated alcohol being formed:

$$R{-}CH{=}CH_2 + H_2O \longrightarrow R{-}CH(OH){-}CH_3.$$

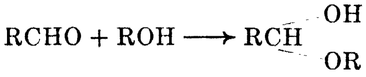
Apply the same reaction to (1) acetylenes, (2) nitriles, (3) imides, (4) ketones.

NOTE. In specifying the final product remember that a hydroxyl attached to a doubly bound atom constitutes an enol, which may tautomerize to a keto form, and, secondly, that certain pairs of groups attached to the same carbon atom constitute unstable combinations.

25. Write balanced equations for the preparation of amines from (1) the reaction of an alkyl halide and sodamide; (2) the reduction of a nitrile by sodium amalgam; (3) the reaction of ammonia and an alkyl halide; (4) the hydrolysis of an alkyl-substituted acid amide; (5) the reduction of a nitro derivative by tin and an acid.

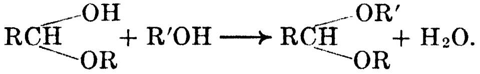
26. What is a lactone? an acetal? an inner ether? an ethylene oxide? an amylene oxide? a semiacetal?

27. An acetal is formed in two steps:



$$RCHO + ROH \longrightarrow RCH\begin{matrix}OH\\OR\end{matrix} \tag{1}$$

and



$$RCH\begin{matrix}OH\\OR\end{matrix} + R'OH \longrightarrow RCH\begin{matrix}OR'\\OR\end{matrix} + H_2O. \tag{2}$$

Apply these two reactions to glucose, using, in place of ROH, as above, the carbinol group in the δ-position with respect to the aldehyde group in the same molecule, and for R′OH use methyl alcohol.

28. Write the structural formula of tetramethyl-methyl-glucoside. If this compound is subjected to gentle hydrolysis, only one methyl group is split off as methyl alcohol. Write the structural formula of the hydrolyzed product.

NOTE. Acetals are more rapidly hydrolyzed than are ethers.

29. An acid produced by hydrolysis of an ester is thought to be butyric acid. Consider that 10 g. of ester has been hydrolyzed by 100 cc. of strong sodium hydroxide. Outline a procedure which could be used for each of the following confirmations: (1) the acid is isolated and its boiling point is determined; (2) the acid is converted into its ethyl ester and the boiling point of the pure ester is determined; (3) the acid is converted into the acid chloride, and the latter into the anilide, whose melting point is determined. What use can be made of the determination of the equivalent weight of a pure acid as an aid in its identification?

30. What evidence of the presence of palmitic, stearic, or oleic acids should you expect to obtain during the steam distillation of an alkaline solution containing them? How could you use bromine water to distinguish the last from the first two acids?

31. Devise a method for handling 1 cc. of methyl salicylate in each of the following operations: (1) determine the boiling point;

(2) wash with dilute alkali, dry with anhydrous calcium chloride, and recover pure in 90 per cent yield.

32. Which of the following reactions should you expect to be the faster: (1) the ammonolysis of an ester or of an ether, (2) the hydrolysis of an alkyl chloride or of an acid chloride, (3) the hydrolysis of an acid amide or of an alkyl amine, (4) the ammonolysis of an alkyl chloride or of an acid chloride, (5) the ammonolysis or the hydrolysis of an acid chloride, (6) the hydrolysis of a nitrile or of an ethylene, (7) the esterification by ethyl alcohol of sulphuric acid or of acetic acid, (8) the esterification by ethyl alcohol of phosphoric acid or of hydrogen chloride?

33. Name three types of organic reactions that are reversible and three that are irreversible.

34. If *p*-xylene ($C_6H_4(CH_3)_2$) were brominated at 100° in sunlight, what would be formed? At 50° in the presence of iron filings, what bromination product would be formed?

35. If ethyl benzene were brominated at 100° in sunlight, would the bromination take place to the greater extent on the α-carbon or on the β-carbon of the side chain? If ethyl benzene were oxidized by chromic acid, which carbon atom would be first attacked? What would be the final product?

Memorize the directing influence of the following groups when present in the benzene ring: nitro, methyl, halide, aldehyde, carboxyl, sulphonic acid, hydroxyl, amino, alkyl.

36. How would *p*-aminophenol be prepared from nitrobenzene?

NOTE. Make use of the Hofmann type of rearrangement.

37. State how the bromination of a ketone and the aldol condensation indicate the relative reactivity of hydrogen on the carbon atoms in the α and β positions with respect to the carbonyl group.

38. Write structural formulas for possible tautomeric forms of each of the following: nitrosophenol, nitrophenol, benzaldehydephenylhydrazone, and benzaldoxime.

39. Sulphanilic acid is a high-melting compound, whereas the groups NH_2 and SO_3H are generally found in compounds that are liquids or low-melting solids. Explain.

40. Write the structural formula of the oxime of an acid. It is called a hydroxamic acid. In its tautomeric form it resembles a hydroxy acid amide. Are such compounds prepared by methods resembling oxime formation from ketones or by methods resembling amide formation from acids?

41. What is the acetoacetic ester condensation? How would benzaldehyde condense with propionic ester in the presence of sodium ethylate?

NOTE. α-Methyl β-phenyl crotonic ester is formed.

Write the reaction and draw the analogy between this reaction and Perkin's synthesis of unsaturated acids in regard to the reagents and to the type of catalyst used. Does the acetoacetic ester type of condensation take place with the free acids or with metallic salts of acids as it does with esters?

42. Predict from the method of formation of ethyl magnesium iodide the relative rapidity of the two reactions

$$C_2H_5I + Mg \longrightarrow C_2H_5MgI$$

and

$$C_2H_5MgI + C_2H_5I \longrightarrow C_4H_{10} + MgI_2.$$

43. In the series of reduction reactions, nitrobenzene ⟶ azoxybenzene ⟶ azobenzene ⟶ hydrazobenzene ⟶ aniline, which is the slowest when zinc dust in alkali is used as the reducing agent? Which is the slowest when methyl alcohol in alkali is used?

44. In the preparation of methyl orange, why is the sulphanilic acid first dissolved in alkali?

45. Under what circumstances can phenyldiazo chloride and phenyldiazo cyanide be made to yield phenyl chloride and phenyl cyanide respectively? Under what circumstances will a diazo chloride or a diazo hydroxide react rapidly with a phenol or an aromatic amine to yield an azo derivative?

46. Does the fact that carbon dioxide precipitates phenol from a concentrated solution of sodium phenolate prove that carbonic acid is a stronger acid than phenol? What facts must be known in order to compare the strengths of two acids?

47. What connection is there between the fact that a solute lowers the vapor pressure of a liquid solvent and the fact that a soluble impurity lowers the melting point of a solid?

48. Which would have the greater effect in lowering the melting point of benzoic acid: 1 per cent by weight of benzophenone or 1 per cent by weight of methyl alcohol? Explain your answer.

49. Make a list of all the classes of compounds studied, and state for each class a reaction so characteristic of that class that it could be used to identify an unknown as belonging to that type. Refer to Part III and note the reactions that are found useful in practice for this purpose.

50. If a substance were known to be either an alcohol, an aldehyde, or an ester, what tests should you use to identify the class to which it belongs?

51. How should you obtain phenol from a mixture of phenol and hydrocarbons when the boiling points are such that they cannot be separated by fractional distillation?

PART III. CLASS REACTIONS

A SYSTEM OF QUALITATIVE ANALYSIS

A graphic formula is assigned to a compound on the basis of its elementary composition, its molecular weight, and its chemical behavior. Structural relationships may be divided into two classes: first, genetic relationships which are based upon the possibility of forming one substance from another; second, relationships which are based upon similarities in physical properties and chemical behavior. The first set of relationships rests upon preparative or synthetic operations. The second, with which we are here mainly concerned, involves the study of specific types of reactions.

Compounds belong to the same class when they exhibit similarity in chemical properties or undergo the same types of reactions. These likenesses are expressed in terms of structural formulas, and such compounds are said to possess the same, or similar, groups of atoms within the molecule. Reactions may be found which are characteristic of specific groups or radicals. Such reactions may be made the basis of a system of qualitative analysis for those groups. Since a single class of compounds may undergo many reactions it has been necessary to determine which reaction is the most suitable to use as the basis of a test for that class. Also since similar results are often observed when different classes of compounds are treated with the same reagent, even though the actual reaction products are of a different type, the selected tests have had to be arranged in such an order as to avoid ambiguity in the interpretation of the result.

The tests for the various classes of compounds have been arranged in five divisions, according to the elements involved in the reactions, as follows:

Division I. Compounds containing carbon and hydrogen, or carbon, hydrogen, and oxygen.
Division II. Compounds containing nitrogen.
Division III. Compounds containing sulphur.
Division IV. Compounds containing a halogen.
Division V. Compounds containing a metal.

In Division I the basis of each test is a reaction involving the element carbon, hydrogen, or oxygen, or some combination of these elements. In Division II each test depends upon some reaction of the nitrogen atom or of some radical containing nitrogen. If a substance contains a very characteristic carbon, hydrogen, and oxygen radical, such as the carboxyl group, and at the same time contains a characteristic nitrogen radical, such as the nitro group, it could conceivably be tested under each of the Divisions I and II. On the other hand, if a compound is acidic, the ionizing hydrogen could come from a carboxyl group, a phenolic or enolic hydroxyl group, a sulphonic acid, an acid amide, or possibly a primary or secondary nitro compound. Certification of the divisions to which the compound does not belong eliminates some of the possibilities. A compound may always be examined by the tests under Division I, even if nitrogen, sulphur, a halogen, or a metal is present, provided that the specific tests used are in no way similar to tests used in Divisions II, III, IV, and V. It is advisable to carry out the tests in the latter divisions first, if the corresponding elements are present, and then to consider the possibility of obtaining further information by utilizing the tests under Division I. For instance, both hydrazines and aldehydes reduce Tollen's reagent, and both esters and aliphatic halides yield acids upon hydrolysis. Tests based upon these reactions must be interpreted with reference to the elements present.

If a compound contains both nitrogen and sulphur, the tests under Division II should be applied before those under Divisions III or I. If the compound contains a metal, the procedure outlined under Division V should be applied first. It is immaterial whether the tests under Division IV are applied before or after those under Divisions II and III.

Within each division the tests for each class of compounds are arranged in a certain order to avoid ambiguity in the interpretation of the results. Each test is accompanied by a statement of the fundamental reaction employed and the limitations which govern its usefulness. There is also with each test a summary of other reactions which, in some circumstances, might be considered characteristic of the class in question, with sometimes a suggestion as to why they are not as applicable as is the test which is outlined in detail. A given test may include several classes of compounds. In such cases the test is given in several sections. The first section is usually designed to show the presence of any one of the types of compounds under consideration, and the subsequent sections are specific for one or more of the possibilities, tending to prove their presence or to eliminate them one by one. *A thorough understanding of the basis of each operation will disclose the general or specific character of the test and will indicate the proper interpretation to be placed upon each experimental observation.*

It is assumed in the application of the tests that relatively simple substances are being investigated. It may or may not be possible, by the procedures outlined, to detect the presence, in a single compound, of two or more characteristic groups. Moreover, some compounds may fail to react, owing to excessive insolubility or to the phenomenon termed steric hindrance, or may react in a manner different from that expected under the conditions of the test, even though they contain the required groups. Some of these limitations have been mentioned in the discussions of the tests themselves.

When it is known to which class a substance belongs, the particular member of that class which it represents may best be ascertained by a comparison of its physical properties with those of known compounds. Convenient lists of the more important compounds have been compiled by Mulliken * and by Kamm.† The latter has based his classification upon solubility determinations. The purpose of this work is not simply to determine the identity of an unknown compound but to obtain a clear perception of the reactions to be associated with a given structural formula and a thorough understanding of the principles underlying the experimental procedure.

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* Mulliken, The Identification of Pure Organic Compounds. John Wiley & Sons, Inc.

† Kamm, Qualitative Organic Analysis. John Wiley & Sons, Inc.

The type of work and the directions given assume experience in qualitative and quantitative analysis, and training in the ordinary methods of organic preparation.* It is always advisable, even for the trained observer, to make tests upon compounds of known composition and structure before proceeding to an unknown case. Such an operation may be called a blank test. Successful results will be obtained only by careful observation, even to minute details, and by the search for a rational explanation of every observation.

PREPARATION OF THE UNKNOWN FOR ANALYSIS

Purification. Crude substances, or those of doubtful purity, should be subjected to the usual methods of purification. The methods most frequently employed involve fractional crystallization and fractional distillation. Often a derivative of the unknown may be prepared which can be purified more readily than the original compound. For example, if difficulty is encountered in the purification of an acid, it may be converted into an ester which is easily purified. Another example of wide application is the separation of acidic, basic, and neutral substances through the formation of salts.

Pure substances are characterized by a homogeneous appearance, sharp melting point, and constant temperature of distillation. The possession of such characteristics does not insure purity, but the absence of them denotes the presence of impurities. For instance, constant-boiling mixtures exist, solutions are homogeneous, substances sometimes crystallize as mixed crystals and form eutectics of constant melting point. On the other hand, many pure substances melt indistinctly, as, owing to their decomposition, they are no longer pure at the temperature of fusion.

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* The student should familiarize himself with the content and methods of use of the following books: Houben-Weyl, Die Methoden der organischen Chemie; Beilstein, Handbuch der organischen Chemie; Lassar-Cohn, Arbeitsmethoden der organischen Chemie; Kingscott and Knight, Methods of Quantitative Organic Analysis.

If decomposition takes place when a substance is melted, the temperature at which the change occurs may depend upon the rate of heating. In no case should the bath be heated so rapidly as to cause an appreciable lag in the thermometer, and it is better, when decomposition is suspected, to plunge the sample into the bath at successively higher temperatures until a reproducible decomposition temperature can be obtained. If the melted sample recrystallizes on cooling, and no decomposition has taken place, the same melting point will again be observed, but decomposition will produce a mixture having a lower and indefinite melting point. Solvent of crystallization will always be removed by continuous heating well below the decomposition point, and an escaping solvent must not be confused with volatile substances produced by decomposition.

Decomposition of a low-boiling liquid during distillation seldom occurs, and with high-boiling liquids decomposition is usually accompanied by charring or the production of colored substances. In case of doubt, distillation should be made in vacuo. It is always advisable to boil a small quantity of the substance in a test tube, to see if it decomposes on distillation, before proceeding with the whole sample.

Special care must be taken with substances liable to variable composition, such as those containing water, alcohol, benzene, or other solvent of crystallization. In melting such substances a boiling or apparent evolution of gas may be noticed, with temporary appearance of a liquid phase, followed by solidification to a substance of higher melting point. In every case a weighed sample of the substance should be dried in a desiccator to constant weight. If constant weight is not attained in a desiccator at room temperature, the failure is probably due to a very slow removal of solvent of crystallization. The drying may be hastened by heating the substance in an air bath at a temperature below its melting point. If the substance is not volatile, a constant weight will be obtained when the solvent has been removed.

It is not always necessary to remove solvent of crystallization. A substance may be considered pure, for analytical purposes, if it has a definite and constant composition. If, however, there is evidence of partial loss of solvent of crystallization on air drying, care must be taken to remove the solvent completely before an analysis is made.*

A substance must be chemically pure before a qualitative or quantitative analysis is made, if the analysis is to be used either to identify the compound or to determine its empirical formula. Very often an analysis is made in order to determine the amount of a given substance present in a mixture. In this case the nature of the impurity, if there is any, must be known, so that an analytical procedure may be adopted which will differentiate the components of the mixture. If the quantity of triphenylchloromethane in a crude sample were determined on the basis of the percentage of chlorine, and any impurity containing chlorine were present, the result would obviously be erroneous. But if the impurity contained no chlorine, then the chlorine content of the sample would furnish a basis for the calculation of the percentage of triphenylchloromethane in the mixture. Very often highly colored impurities are difficult to remove completely, but they may be present in such minute quantities as to introduce no error comparable to the unavoidable errors of analysis.

The degree of purity necessary before the tests for groups are applied depends upon the sensitiveness of the tests used. For instance, the presence of a phenol as an impurity would not vitiate the test for an acid, but an aldehyde as an impurity in an alcohol would lead to false conclusions as to the nature of the substance if the Schiff reagent test were applied.

Purified substances should be kept in the dark in desiccators or in tightly stoppered bottles.

EXAMINATION OF THE PURIFIED PRODUCT

Before proceeding to the tests for characteristic groups the substance should be carefully examined for clues as to the type of compound it represents. Classifications cannot be made inclusive nor exclusive, and therefore the following outline should be taken merely as a list of suggestions.

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* A clue as to whether loss of weight is due to removal of hygroscopic moisture or other volatile impurities, or to solvent of crystallization, may be obtained by calculating the molecular weight of the substance on the assumption that the solvated molecule contained one molecule of solvent. The great majority of crystalline organic compounds have molecular weights below 300. If the calculation results in an unusually high value, the loss in weight is probably due to the escape of a volatile impurity.

Elementary analysis. A qualitative analysis for the elements present should be made as a basis for assigning the compound to one of the five principal divisions.

For the methods of analysis for the nonmetallic elements see page 55. To detect the presence of a metal burn the substance in a porcelain crucible and ignite the ash until all carbonaceous material has been removed. The residue contains the metal in the form of the oxide, carbonate, or some other simple salt, and may be analyzed by the methods usually employed in inorganic qualitative analysis.

Physical constants. The melting point and the boiling point of the unknown will have been taken in the course of purification. In using these physical constants to identify the compound, attention should be directed to a correction for thermometer stem exposure and for barometric pressure.

The physical constants of the members of a homologous series vary with their position in the series. For example, there is a gradual increase in the boiling points of the normal hydrocarbons with increasing molecular weight. There are still more marked dissimilarities in the properties of corresponding members of different homologous series. It is therefore impossible to assign a substance of unknown molecular weight to a particular class on the basis of a single physical property. However, valuable hints as to the nature of a compound may be obtained from a comparison of its physical properties with those of known substances, particularly if the basis of comparison includes several such properties. Thus a low-boiling substance could not be a hydrocarbon if it were soluble in water, nor could a water-soluble substance be an alcohol if it boiled below 60°.

Other examples of the above correlation between physical properties on the one hand and type of structure and molecular weight on the other, may be obtained from the following lists of classes of compounds. In each class the boiling point of the first member in each series and the boiling point of a higher member (usually one containing five carbon atoms) are given. Some data concerning densities and solubilities in water are also included.

SOME PHYSICAL PROPERTIES OF THE LOWER MEMBERS OF CERTAIN CLASSES OF COMPOUNDS

CLASS OF COMPOUND	FORMULAS	BOILING POINT	SPECIFIC GRAVITY	SOLUBILITY IN WATER IN GRAMS PER 100 CC.
Hydrocarbons				
Methane series	CH_4	-160°	—	i.*
	$CH_3-CH_2-CH_2-CH_2-CH_3$	36.3°	—	i.
Ethylene series	$CH_2=CH_2$	-103°	—	i.
	$CH_3-CH_2-CH=CH-CH_3$	36°	—	i.
Acetylene series	$CH\equiv CH$	-81°	—	i.
	$CH_3-CH_2-C\equiv C-CH_3$	56°	—	i.
Ethers	CH_3-O-CH_3	-23.6°	—	i.
	$CH_3-CH_2-O-CH_2-CH_3$	35°	0.719	8.3 g.
Aldehydes	$HCHO$	-21.0°	0.815(-20°)	s.
	$CH_3-CH_2-CH_2-CH_2-CHO$	103.0°	0.819 (11°)	sl. s.
Alkyl halides				
Chlorides	CH_3Cl	-24.0°	0.952 (0°)	400 cc.
	$CH_3-CH_2-CH_2-CH_2-CH_2Cl$	107.0°	0.883 (20°)	i.
Bromides	CH_3Br	4.5°	1.732 (0°)	sl. s.
	$CH_3-CH_2-CH_2-CH_2-CH_2Br$	129.0°	1.223 (20°)	i.
Iodides	CH_3I	45.0°	2.293 (18°)	1.4 g. (20°)
	$CH_3-CH_2-CH_2-CH_2-CH_2I$	156.0°	1.517 (20°)	i.
Amines				
Primary	CH_3NH_2	-7.0°	0.699(-11°)	1150 cc. (12°)
	$CH_3-CH_2-CH-CH_2-CH_2NH_2$	104°	0.766 (19°)	s.
Secondary	$(CH_3)_2NH$	7.0°	0.687 (-6°)	v. s.
	$(C_2H_5)_2NH$	56.0°	0.712 (15°)	v. s.
Tertiary	$(CH_3)_3N$	3.5°	0.662 (-5°)	v. s.
	$(C_2H_5)_3N$	90.0°	0.733	v. s.
Mercaptans	CH_3SH	5.8°	—	i.
	$CH_3-CH_2-CH_2-CH_2-CH_2SH$	120.0°	0.840	i.
Esters	$HCOOCH_3$	32.3°	0.980	30.4 g. (20°)
	$CH_3-CH_2-CH_2-COOCH_3$	102.3°	0.919 (0°)	sl. s.
Acyl halides				
Chlorides	CH_3COCl	51.0°	1.105 (20°)	dec.
	$(CH_3)_2CH-CH_2COCl$	115.0°	0.989 (20°)	dec.
Bromides	CH_3COBr	81.0°	—	dec.
Iodides	CH_3COI	108.0°	1.980 (17°)	dec.
Ketones	$CH_3-CO-CH_3$	57.0°	0.797 (20°)	∞
	$C_2H_5-CO-C_2H_5$	103.0°	0.814 (20°)	s.
Alcohols	CH_3OH	64.5°	0.791 (20°)	∞
	$C_5H_{11}OH$ (n)	138.0°	0.817 (20°)	2.7 g. (22°)
Oximes	$H_2C=NOH$	84.0°	—	dec. h.
	$(CH_3)_2C=NOH$ †	135.0°	0.887 (75°)	v. s.
Acids	$HCOOH$	100.8°	1.218 (20°)	∞
	C_4H_9COOH (n)	185.0°	0.956 (0°)	3.7 g. (16°)
Anhydrides	$(CH_3CO)_2O$	137.0°	1.080 (15°)	dec.
	$(C_4H_9CO)_2O$ (iso)	215.0°	0.929 (27°)	dec. h.
Amides	$HCONH_2$	192.0°	1.337	∞
	$C_4H_9CONH_2$ (iso) †	232.0°	—	s.

* *Abbreviations*: dec., decomposes; h., hot; i., insoluble; s., soluble; sl., slightly; v., very; ∞, soluble in all proportions.

† Solid at room temperature.

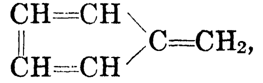
The following list of aromatic compounds is limited to single representatives of various classes. The compound listed is the lowest-boiling member of its class. Thus, toluene, included in the table, boils at a lower temperature than xylene or any other alkyl derivative of benzene.

Some Physical Properties of Typical Aromatic Compounds

Compound	Formula	Boiling Point	Specific Gravity	Solubility in Water in grams per 100 cc.
Benzene	C_6H_6	80.4°	0.880 (20°)	0.07 (22°)
Toluene	$C_6H_5CH_3$	111°	0.866 (20°)	i.
Pyridine	C_5H_5N	115°	0.990	∞
Phenyl chloride	C_6H_5Cl	132°	1.106 (20°)	i.
Phenyl bromide	C_6H_5Br	155°	1.491 (20°)	i.
Anisol	$C_6H_5OCH_3$	155°	0.988 (21°)	i.
Phenylisocyanide	C_6H_5NC	166°	0.978	dec.
Thiophenol	C_6H_5SH	168°	1.078	i.
Benzaldehyde	C_6H_5CHO	179.5°	1.05	0.33 g.
Phenol	C_6H_5OH	183°	1.072 (20°)	6.7 g. (16°)
Aniline	$C_6H_5NH_2$	184°	1.022 (20°)	3.1 g. (16°)
Phenyliodide	C_6H_5I	188°	1.861 (0°)	i.
Phenyl cyanide	C_6H_5CN	191°	1.000 (25°)	1.0 (100°)
Methyl benzoate	$C_6H_5COOCH_3$	199°	1.094	v. sl. s.
Nitrobenzene	$C_6H_5NO_2$	210°	1.204 (20°)	v. sl. s.
Naphthalene	$C_{10}H_8$	218°	1.152	i.
Quinoline	C_9H_7N	236°	1.090	sl. s.
Benzoic acid	C_6H_5COOH	249°	1.266	0.29 g. (20°)
Diphenyl ether	$(C_6H_5)_2O$	253°	1.083 (20°)	v. sl. s.
Benzamide	$C_6H_5CONH_2$	290°	1.341	sl. s. h.
Diphenyl sulphide	$(C_6H_5)_2S$	296°	1.119 (15°)	i.

A compound has the odor of an ester. Its equivalent weight (determined by hydrolysis and titration of the alkali used) is found to be about 160. Its boiling point is 180°. What is the probability of being able to obtain a solid acid from such an ester?

A compound gives a positive test for an aromatic nucleus. (A color is produced when the substance is heated with $AlCl_3$ and $CHCl_3$.) It boils at 140° and is insoluble in water. In an attempt to identify this substance, which classes of compounds are eliminated from consideration?

Color. If carbon, hydrogen, and oxygen only are present, color establishes a strong presumption that the compound has an aromatic nucleus. Some aliphatic nitrogen compounds are colored, as, for example, the salts of the nitrolic acids; but nearly all aliphatic compounds containing carbon, hydrogen, and oxygen only are colorless. Among the exceptions are compounds having two or more carbonyl groups in a continuous chain. Diacetyl, $CH_3—CO—CO—CH_3$, is yellow, and the triketone $CH_3—CO—CO—CO—CH_3$ has an orange color. The ketenes, $R_2C{=}CO$, are colored. Some unsaturated cyclic hydrocarbons that are closely related to the aromatic series possess color. Fulvene, , and its derivatives are examples of this class. A few aliphatic compounds containing sulphur are colored.

Odor. Esters in general have pleasant, fruity odors, although terpenes and many ketones and aldehydes could be mistaken for esters. Mercaptans, isonitriles, thioethers, amines, acid halides, and other volatile substances have characteristic odors. The absence of a strong odor is often as significant as its presence.

Taste. Polyhydroxy compounds are sweet; acids, with the exception of some amino acids, are sour; alkaloids are bitter. Care should be taken to use extremely small quantities when tasting poisonous substances.

Crystalline form. This characteristic property is seldom used in identifying substances. Crystalline forms are sometimes altered by change of solvent or temperature of crystallization.

Solubility. The solubility of a substance will offer a very valuable clue to its nature. In measuring solubility it must be remembered that many solids dissolve slowly and that mere contact for a short time between the crystals and solvent does not necessarily produce a saturated solution.

For crystallization the temperature coefficient of solubility is more important than actual solubility, but this does not concern the determination of solubility as indicative of the type of compound. In general, substances dissolve in similar substances. Hydroxyl groups increase solubility in water and decrease solubility in ether; hydrocarbon groups decrease solubility in water and increase it in ether. The solubility of one member of a homologous series does not indicate the solubility of another, especially if the two are far removed from each other in the series.

Salts are often more soluble in water than are the corresponding acids or bases; hence, in cases where the latter are sparingly soluble in water they may be found to dissolve readily in dilute solutions of strong bases and acids respectively. Conversely, an increase in solubility of a substance in base or acid over that in water may be taken as indicative of acidic or basic properties. However, if a substance does not behave in this way it must not be concluded that it is neutral in character, since the salt may be less soluble than either of its constituents. For example, an acid will form a salt when treated with a base, but if the acid is insoluble in water, and if the salt formed is also insoluble, it may not be apparent that any change has occurred. It may be necessary in such a case to isolate and dry the solid residue and to determine from its melting point or other properties whether it is the unchanged substance or a salt. In other cases the comparatively crude methods used to compare the solubilities of a substance in the various solvents do not detect very slight increases in solubility.

The following table of solubilities was originally prepared by Kamm and his associates at the University of Illinois. It is reproduced here and will be found in modified form in Kamm's "Qualitative Organic Analysis." In the application of this table actual solubilities are not so important as the comparative solubilities in the different solvents.

SOLUBILITY TABLE

SOLUBLE IN WATER

Soluble in ether

1. Aliphatic monobasic acids
2. Alcohols (low mol. wt.)
3. Aldehydes (low mol. wt.)
4. Ketones (low mol. wt.)
5. Amines (low mol. wt.)
6. Some phenols
7. Aromatic diamines
8. A few esters (low mol. wt.)
9. Amino acids (low mol. wt.)
10. Oximes (low mol. wt.)
11. Acid halides (with hydrolysis)
12. Some anhydrides (with hydrolysis)

Insoluble in ether

1. Polyhydric alcohols
2. Sugars (including soluble starches and glucosides)
3. Many polybasic acids and hydroxy acids
4. Amides (some)
5. Sulphonic and sulphinic acids
6. Some inorganic esters
7. Quaternary-ammonium compounds
8. *Many salts*

INSOLUBLE IN WATER

BASIC SUBSTANCES

Soluble in dilute HCl but insoluble in H_2O

1. Some amines
2. Some cyclic N compounds
3. Many alkaloids
4. Hydrazines

(Under amines we include also amino phenols, amino acids, etc.)

ACIDIC SUBSTANCES

Soluble in dilute KOH but insoluble in H_2O

1. Phenols
2. Acids (high mol. wt.)
3. Some amides
4. Imides
5. Nitrosophenols and most polynitro compounds
6. Primary and secondary nitro compounds
7. Mercaptans
8. Oximes
9. Enolic substances
10. Sulphonyl derivatives of primary amines

INSOLUBLE IN WATER, DILUTE ACIDS, OR BASES

Soluble in cold concentrated H_2SO_4

1. Alcohols (high mol. wt.)
2. Aldehydes (high mol. wt.)
3. Ketones (high mol. wt.)
4. Ethers (high mol. wt.)
5. Acid halides (high mol. wt.)
6. Anhydrides (high mol. wt.)
7. Unsaturated hydrocarbons
8. Esters and lactones
9. Amides (including negatively substituted amines)
10. Nitriles
11. Tertiary nitro compounds
12. Various sulphur compounds

Insoluble in cold concentrated H_2SO_4

1. Aliphatic saturated hydrocarbons
2. Aromatic hydrocarbons
3. Halogen substitution products of above

CONFIRMATION OF THE IDENTITY OF A SUBSTANCE

When the available data, such as physical properties, elementary composition, tests for groups, etc., indicate a certain compound, it may be necessary to confirm the identity by some of the methods enumerated below.

Determination of mixed melting point. If the substance is a solid, the melting point of a mixture of the unknown and a sample of known material may be taken. If the melting point of the mixture is the same as that of each of the separate components, the components are identical.

Analysis. A quantitative determination of at least one of the elements or groups present may be made.

Molecular-weight determination. Any standard method may be used to determine the molecular weight. For references to the literature see page 48.

Preparation of a derivative. Some derivative of the unknown may be prepared in small quantity, preferably a solid derivative and one whose properties are known. Liquid derivatives must be made in larger quantities to facilitate purification.

Preparation of unknown. The unknown may be prepared by such reactions as will establish the structure of the compound.

DIVISION I. COMPOUNDS CONTAINING CARBON AND HYDROGEN OR CARBON, HYDROGEN, AND OXYGEN

TEST 1. ACIDS AND SOME ANHYDRIDES, LACTONES, AND EASILY HYDROLYZED ESTERS

The most characteristic reaction of a carboxylic acid (that is, of the COOH group) is its dissociation in water into the hydrogen ion, H^+, and the negative ion, $RCOO^-$. The extent of this reaction is represented by its dissociation constant K_a. The constant is defined by the equation

$$K_a = \frac{(H^+)(RCOO^-)}{(RCOOH)}.$$

A symbol or a formula inclosed within parentheses is used to represent the concentration of the substance in mols per liter. With the majority of organic acids the dissociation constants have approximately the value of 10^{-5} mols per liter. In a 1 N solution of such an acid the hydrogen ion concentration is about 3×10^{-3} N, approximately $\frac{3}{10}$ per cent of the acid being dissociated (see page 246). An acid having a dissociation constant as great as 1×10^{-5} can be titrated accurately with sodium hydroxide when phenolphthalein is used as an indicator. The simplest test for the COOH group is based on this property

(Test 1a). Even the second and higher dissociation constants of polybasic acids are large enough to permit an accurate titration when phenolphthalein is used as an indicator.*

From the result of the titration the equivalent weight of the unknown acting as an acid is calculated. If the calculated value of the equivalent weight is less than 400, the test is positive for a carboxyl group.† This method for determining the equivalent weight of an acid is accurate if the proper indicator is used and if equilibrium is attained in the process. The criteria for a satisfactory titration are a sharp end point which is permanent for at least fifteen seconds, and a clear solution when the titration is completed. Consult Part IV for a discussion of the titration process and the determination of equivalent weights. If the titration is not entirely satisfactory, no reliance can be placed upon the calculated numerical value of the equivalent weight. The titration may, however, be good enough to warrant a decision concerning the presence or absence of a carboxyl group.

If the calculated equivalent weight is greater than 400, the substance is not a carboxylic acid. In this case the neutralization of a small but appreciable amount of alkali should be taken as evidence either that the substance contains an acidic group much weaker than the carboxyl (for example, the hydroxyl group in a phenol), or that it is slowly reacting to form an acid, as in the hydrolysis of an ester, or that some acid impurity is present. The titration of a very weak acid or of a slowly hydrolyzing substance results in an indefinite end point.

Any substance that reacts rapidly with water at room temperature to yield an acid will respond to Test 1a. The anhydrides of the lower fatty acids cannot be distinguished from the free acids by titration alone. Methyl formate and a few other soluble esters also hydrolyze rapidly enough to act like acids. If the substance being tested is acidic upon titration and is sparingly soluble in cold water, the simple procedure outlined in Test 1b will permit it to be distinguished as an acid, on the one hand, or as an easily hydrolyzed ester, acid anhydride, or lactone on the other. The preliminary examination already given to the substance may have eliminated one of these claims from consideration (see page 138). Test 1b is based on the fact that if a water-insoluble acid dissolves in alkali, it may be reprecipitated in its original form by the addition of a strong acid to the solution; but if an insoluble ester, an acid anhydride, or a lactone dissolves in alkali, it does so through hydrolysis, and any acid precipitated from such a solution will not have the properties (melting point, equivalent weight, etc.) of the original substance. If no substance is precipitated on acidifying the alkaline solution, it means either that a mistake was made in estimating the solubility of the original substance in water or that a change has occurred through solution in alkali. The reprecipitated acid is collected and dried, and its melting point determined. A weighed sample of it is titrated as in Test 1a, and from the result the equivalent weight of the acid is calculated. If this value agrees with that obtained by titration of the original substance, the substance is an acid; if it is nine units greater, it is an acid anhydride; and if it is eighteen units greater, it is an easily hydrolyzed cyclic ester, that is, a lactone. An increase of nine in equivalent weight means that one molecule of water (mol. wt. 18) has been used in producing two equivalents of acid. If the equivalent weight of the dissolved and reprecipitated substance is less than that of the original, the unknown is an ordinary ester.

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* The second dissociation constant of carbonic acid is exceptional, and carbonic acid acts like a monobasic acid when a cold solution is titrated in the presence of phenolphthalein. That is to say, the end point is reached when only one of the hydrogen ions in the hypothetical H_2CO_3 has been neutralized.

† Keep in mind the fact that this statement applies to Division I only, that is, to compounds containing carbon, hydrogen, and oxygen exclusively. Acids having molecular weights above 400 exist, but they are comparatively rare. This value is adopted arbitrarily, and the student must not overlook the possibility that the unknown may be an acid of very high molecular weight.

Only in exceptional cases will the insolubility of an acid interfere with the titration. The rate of solution, however, may be slow, and a substance that dissolves slowly should be finely pulverized before mixing it with the solvent.

The most accurate method for determining the equivalent weight of an acid, and one that can always be applied, is based on an analysis of a salt of the acid. It is, however, a time-consuming procedure. This method must be used to distinguish between acids, esters, and anhydrides when the simpler plan fails.

The silver salt of the acid is prepared by precipitating it with silver nitrate* from the solution obtained by titrating the acid. After the silver salt is washed, dried, and weighed, it is decomposed by heating, and the resulting silver is weighed. From the percentage by weight of silver in the silver salt the equivalent weight of the acid may be calculated and the result compared as above with the equivalent weight of the original substance as obtained by titration.

Test 1a. Weigh out about 0.2 g. of the unknown. If it is a solid, it should first be reduced to a very fine powder. Then add 10 cc. of distilled water and a drop of 10 per cent solution of phenolphthalein, and titrate with 0.1 *N* sodium hydroxide. If the substance is insoluble, the suspension should be shaken vigorously after each small addition of the base, or the substance may be dissolved in alcohol before titrating. It is best to make the titration in an Erlenmeyer flask and to stopper the flask when shaking the mixture. Even then some carbon dioxide may be absorbed from the air, causing a slow but continued disappearance of the end-point color. Calculate the equivalent weight of the unknown.

Test 1b. If an equivalent weight of less than 400 was obtained in Test 1a, determine the solubility of the unknown in water. If it appears to be sparingly soluble and if it dissolved on titration in Test 1a, dissolve about 0.5 g. in 1 *N* sodium hydroxide and then add to the solution an equal volume of 1 *N* hydrochloric acid. Filter off any precipitate on a Gooch crucible, wash with a little water, and dry in a desiccator. Compare this sample in melting point and equivalent weight with the original. If the two samples are the same, the original is an acid. If a precipitate forms which is not identical with the original substance, or if no precipitate is produced on acidifying the solution, the substance is an acid anhydride or an easily hydrolyzed ester. If the original is soluble in water and its other physical properties suggest that it may be an acid anhydride or an easily hydrolyzed ester, dissolve a portion in alkali and prepare from the solution either the sodium salt or the silver salt for analysis. From the percentage of metal in the salt, calculate the equivalent weight of the acid, and compare the result with that obtained from titration of the original substance (Test 1a). If these results are the same, the substance is an acid.

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* The silver salts of some simple acids do not precipitate. Silver acetate, for example, is soluble in water.

Phenols and enols have dissociation constants of the order* of 1×10^{-10}. When titrated with alkalies in the presence of phenolphthalein, the apparent end point is reached when only a small fraction of such an acid has been converted into the corresponding salt. The equivalent weight of a phenol or an enol as calculated on the basis of a titration is many times as great as its actual equivalent weight. (The value ordinarily obtained is well above 400.) On the other hand, there are types of compounds not included in this division that act like carboxylic acids in so far as a titration with alkali is concerned. Among these may be mentioned the sulphonic acids, nitrophenols, N-nitro amines, cyanide-substituted enols and amides, and salts of very weak bases with strong acids, as, for example, the salts of aniline. There are also neutral substances that contain the carboxyl group. The amino acids and salts of carboxylic acids belong to this class of compounds.

When compared with other compounds having the same number of carbon atoms, it will be observed that the acids have relatively high boiling points, high melting points, and high dielectric constants. They are also more soluble in water than are the corresponding members of most of the other series. In the liquid state they are highly associated. They form double molecules in many solvents, and even give evidence of association in the gaseous state. These properties are, in general, characteristic of substances that ionize and substances that, as solvents, promote the ionization of the solute.

Acids react with alcohols to form esters. The reaction is reversible and is catalyzed by hydrogen ions.

$$R \cdot COOH + ROH \rightleftharpoons R \cdot COOR + H_2O.$$

The ammonium salts of the carboxylic acids lose water when heated above 200°, forming acid amides.

$$R \cdot COONH_4 \rightleftharpoons H_2O + R \cdot CONH_2.$$

A similar reaction occurs with organic salts of amines. Thus aniline acetate, when heated, yields acetanilide.

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* Some enols, particularly 1, 3 diketones, have dissociation constants as high as 1×10^{-6}, and, like carboxylic acids, can be titrated accurately with phenolphthalein as indicator.

Acid chlorides are formed when phosphorus pentachloride reacts with carboxylic acids. Many other reagents may be substituted for phosphorus pentachloride, as, for example, phosgene, oxalyl chloride, and sulphuryl chloride.

$$R \cdot COOH + PCl_5 \longrightarrow POCl_3 + HCl + R \cdot COCl.$$

The acid anhydrides can be prepared by heating acid chlorides with the sodium salts of carboxylic acids. They can be obtained also by the direct dehydration of the acids with phosphorus pentoxide at high temperatures.

$$2\ R \cdot COOH \rightleftharpoons (R \cdot CO)_2O + H_2O.$$

Under drastic conditions carbonates can be formed from the salts of carboxylic acids. The sodium salts when heated with soda lime yield sodium carbonate and hydrocarbons.

$$R \cdot COONa + NaOH \longrightarrow Na_2CO_3 + RH.$$

Dry distillation of a calcium salt results in the formation of a ketone and a carbonate.

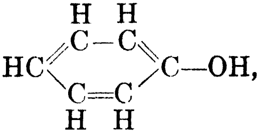
$$(R \cdot COO)_2Ca \longrightarrow CaCO_3 + R \cdot CO \cdot R.$$

As a rule the free acids cannot be directly reduced, but their derivatives (for example, acid anhydrides and chlorides) can be reduced to aldehydes and to alcohols.

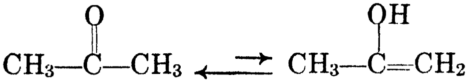
The reactions listed above are useful at times in helping to establish the presence of the carboxyl group. They are much slower than the ionic reaction involved in titration, and they have not the advantage of giving visible evidence of the change involved. The products have to be isolated and identified before the results can be interpreted. Comparatively large quantities of the unknown must be used in the preparation of organic derivatives. For these reasons we rely in most instances upon the titration method outlined above. On account of its simplicity and the value of its quantitative result the neutralization experiment is superior to other tests. It fails, however, when the carboxyl group is neutralized by another group within the same molecule, as, for example, in the amino acids, or when the unknown is a salt from which the free acid is not easily obtained. In such cases one must resort to nonionic reactions.

Test 2. Enols and Phenols

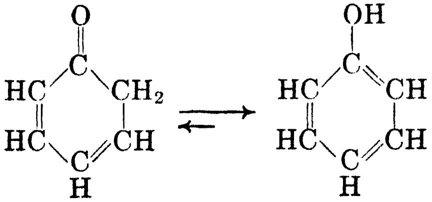
The structure $>C=\overset{\overset{\displaystyle OH}{|}}{C}—$ is characteristic of the enols. This group is in equilibrium with the keto group $>CH—\overset{\overset{\displaystyle O}{\|}}{C}—$. In the case of the simple aldehydes and ketones the equilibrium so greatly favors the keto form that the substances do not give the characteristic tests of the enols. If, however, another carbonyl group is attached to the CH group of the keto form, as, for instance, in acetoacetic ester, $CH_3 \cdot CO \cdot CH_2 \cdot COOC_2H_5$, then at equilibrium the enol form exists at a sufficiently high concentration to allow the substances to respond to these tests. Also, if in the enol form the doubly bound carbon atoms form part of an aromatic ring, as, for instance, in phenol,



then at equilibrium the enol form generally predominates over the keto, and the substance reacts chiefly as an enol. These statements may be summarized by equations. Two arrows are used to indicate that the change in structure is reversible, the longer arrow pointing toward the form that predominates in the equilibrium mixture.



$$CH_3—\overset{\overset{\displaystyle O}{\|}}{C}—CH_3 \underset{\xleftarrow{\hspace{3em}}}{\rightarrow} CH_3—\overset{\overset{\displaystyle OH}{|}}{C}=CH_2$$



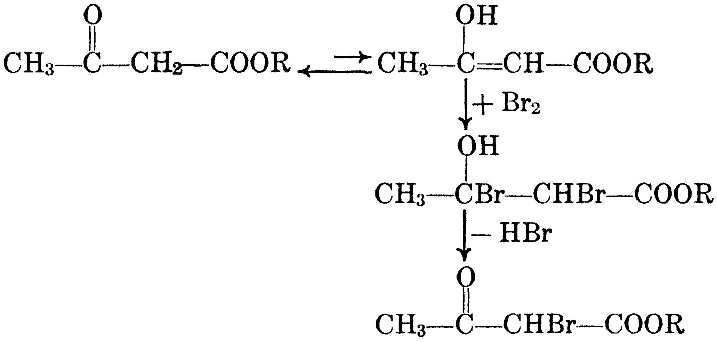
The phenols and enols are much stronger acids than are the alcohols, but they are much weaker than the carboxylic acids and can be distinguished from the latter by their very high apparent equivalent weights as determined by titration when phenolphthaleïn is used as the indicator. On the other hand, they are sufficiently acidic to form salts when treated with dilute sodium hydroxide solution. These salts are generally soluble in water. This reaction is the basis of Test 2b, but it is applicable only if the salt is much more soluble in water than is the free acid. Thus the equilibrium expressed by the following type equation

$$\underset{\text{Solid}}{\text{HA}} \rightleftarrows \underset{\text{Dissolved}}{\text{HA}} \rightleftarrows \text{H}^+ + \text{A}^-$$

may be displaced in favor of the formation of the anion when its hydrogen ion concentration is lowered by the addition of alkali. In excess alkali the solid acid dissolves. A clear solution will be obtained unless the salt formed is sparingly soluble. Even if a clear solution is not obtained, salt formation may have occurred. This may be detected by comparing the solid with the original substance, or, better, by filtering to obtain a clear saturated solution of the salt and acidifying it to precipitate the original acid. Since the sodium salts of the sparingly soluble acids are usually more soluble than the acids themselves, a precipitate is obtained by acidifying a saturated solution of the salt. This is evidently a displacement of the equilibrium represented above to the left.

Test 2a is based on the fact that ferric ions form highly colored complex ions with the ions of many weak acids, including prussic acid, phenols, and enols. In the case of some of the phenols the color is due to the formation of oxidation products by the action of the ferric chloride. This test often fails in the presence of hydrogen ions, owing to the reduction in the concentration of the anion, and so it is not always applicable when both enolic and carboxylic groups are present. For a description of the colors produced by specific phenols see Houben-Weyl's "Die Methoden der organischen Chemie," Vol. II, p. 760 (1911).

Test 2c is based on the reactions of phenols and enols with bromine. In the case of a phenol a hydrogen atom *ortho* or *para* to the hydroxyl group is substituted very rapidly by bromine with the formation of a bromophenol and hydrogen bromide. Enols react with bromine, forming addition products. These readily lose hydrogen bromide, owing to the presence of a bromine atom and a hydroxyl group on the same carbon atom in the addition product. As the enol form is used up by these reactions the keto changes into enol and the reaction proceeds to completion. The action of bromine upon acetoacetic ester is a typical case:



$$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-CH_2-COOR \rightleftarrows CH_3-\overset{\overset{\displaystyle OH}{|}}{C}{=}CH-COOR$$

$$\downarrow + Br_2$$

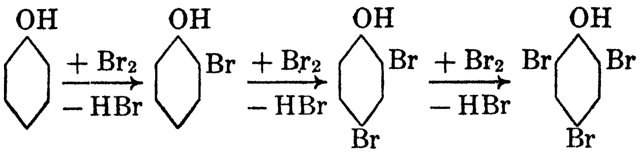
$$CH_3-\overset{\overset{\displaystyle OH}{|}}{C}Br-CHBr-COOR$$

$$\downarrow - HBr$$

$$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-CHBr-COOR$$

The change represented by the horizontal arrows is reversible. The reactions represented by vertical arrows are irreversible processes. The liberation of hydrogen bromide distinguishes this reaction from the addition of bromine to an unsaturated hydrocarbon.

The reaction of a phenol with bromine may go through the same steps as in the case of an enol, but direct evidence of this is lacking. However, the final result is substitution of hydrogen in the *ortho* and *para* positions.



Usually the second and third steps are as rapid as the first, so that complete bromination is the result. Other substituents in the ring alter the number of rapid replacements even if the *ortho* and *para* positions are vacant. If the reaction is carried out in aqueous solution, the formation of a precipitate with rapid decoloration of the bromine can be taken as evidence of a bromination reaction. See Test 7 for a distinction between substitution and addition reactions in aqueous solution.

The reactions of Tests 2b and 2c are rapid, for in each case a powerful catalyst for the keto-to-enol tautomerism is present. The catalyst in 2b is the sodium hydroxide added, and in 2c it is the hydrobromic acid formed.

Test 2b is not applicable when a carboxylic acid group is present, and reliance can be placed on none of these tests when nitrogen is present. Test 2b may be given by a very easily hydrolyzed ester or acid anhydride, and Test 2a by a substance which hydrolyzes very easily to give a phenol.

Test 2a. Shake the liquid or finely divided solid with hot water (about 0.1 g. to 5 cc. of water), cool, filter, and add a 10 per cent ferric chloride solution drop by drop. The ferric chloride solution should not contain excess acid. A coloration, even transient, other than yellow or orange, indicates a phenol or an enol. The test should be tried on an alcoholic solution of the substance if it fails in water.

Test 2b. Shake for a minute 0.1 g. of the substance (finely powdered if a solid) with 5 cc. of 1.0 *N* NaOH. If a clear solution is not obtained, add 10 cc. of water and shake the mixture for another minute. If there is still a solid residue, filter and add 0.5 cc. of 12 *N* HCl to the filtrate. If the substance does not dissolve in water but dissolves in the dilute sodium hydroxide, or if a precipitate is obtained when the filtrate is acidified, the substance is probably a phenol or an enol.

Test 2c. Add to 0.5 g. of the substance 3 cc. of absolute alcohol, then two or three drops of a 5 per cent solution of bromine in carbon tetrachloride.* If the bromine is not rapidly decolorized, the test is negative. If the preliminary test indicates that bromine is being decolorized, add 3 cc. of the 5 per cent bromine solution and shake the mixture for at least a minute. Add 5 cc. of carbon tetrachloride, pour the mixture into a small beaker, and blow your breath across the top of the beaker.* The appearance of white fumes may be expected if the substance is a phenol or an enol. Run a blank test with alcohol, bromine, and carbon tetrachloride for comparison with results obtained with the unknown.

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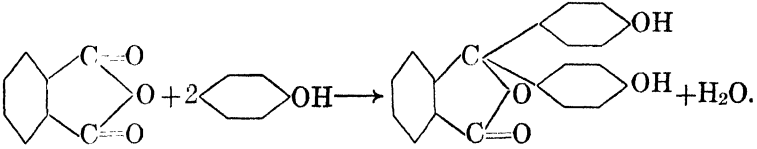
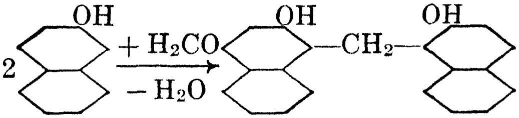
* Increasing the ratio of carbon tetrachloride to alcohol reduces the solubility of the hydrogen bromide.

The phenols give other reactions that are occasionally useful in the detection or identification of individual members. Phthalic anhydride condenses with phenols in the presence of sulphuric acid to give phthaleins.



Resorcin (m-$C_6H_4(OH)_2$) and phthalic acid anhydride yielo fluorescein. Similarly, other carbonyl derivatives condense. Formaldehyde gives a series of resins with phenols known commercially as bakelite. With β-naphthol it reacts as follows:



The formation of condensation products between aldehydes and resorcin has been used as a class test for aldehydes.

Nitration of phenols takes place more rapidly and at a lower temperature than with the corresponding hydrocarbons. The nitration takes place in the *ortho* or *para* positions, or both, and the product serves as a good derivative for the identification of the phenol. Phenols with nitrous acid form nitroso compounds.

Phenols in general, particularly the polyhydric phenols and aminophenols, react in alkaline solution with the oxygen of the air. The solution becomes dark. This behavior is used for the quantitative estimation of oxygen, and the coloration serves as a good indication of a phenolic compound. The reaction is of the type

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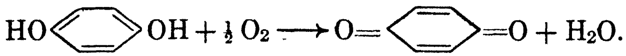
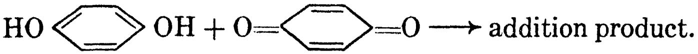
* A rod moistened with ammonia water and held over the beaker is a more sensitive test; but if this test is used, a very faint appearance of fumes should not be regarded as a test for a phenol or an enol.


Hydroquinone (colorless) Quinone (yellow)

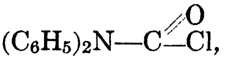

Quinhydrone (dark color)

The formation of azo dyes from phenols and diazotized aromatic amines is a rapid reaction. The appearance of color or of a precipitate is an indication that the reaction has taken place, and in the absence of nitrogen in the unknown serves as a good test for a phenol.

The above reactions involve a reactive nuclear hydrogen and may occur with other aromatic derivatives, notably with aromatic amines. Some reactions involving the hydroxyl group not used in the tests may be mentioned.

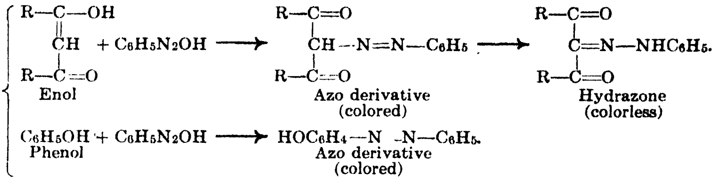
Ether formation proceeds as with other hydroxy derivatives. Alkyl sulphates and alkyl halides react with sodium phenolates, the following in particular giving easily recognized derivatives (*J. Am. Chem. Soc.*, **42**, 615 (1920)):

$$C_6H_5ONa + ClCH_2C_6H_4NO_2 \longrightarrow C_6H_5OCH_2C_6H_4NO_2 + NaCl.$$

Acid chlorides react with phenols to form esters. The chloride of diphenylcarbamic acid,  $(C_6H_5)_2N\text{—}\overset{\displaystyle /\!\!/ O}{C}\text{—}Cl$, forms esters more rapidly with phenols than with alcohols. Phenols add to phenylisocyanate to form substituted carbonic esters as do alcohols (see page 184). Any reaction which removes the oxygen from the nucleus is in general very slow. Hence the type reaction with phosphorus trichloride to form a halide does not take place. A striking exception is found in picric acid, which readily gives picryl chloride; but here the OH has been activated by nitro groups. Naphthols react with ammonia at high temperatures and pressures to form amines.

The enols give some of the above reactions. The products, however, are often of a different type from those yielded by the phenols. A few examples will suffice:

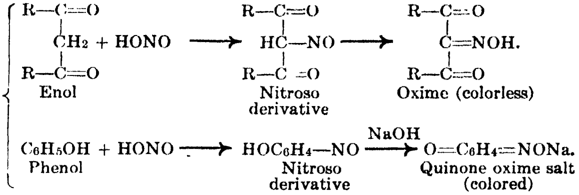
I



$$\begin{array}{l}R—C—OH\\ \quad\;\|\\ \quad\;CH\\ \quad\;|\\ R—C=O\end{array} + C_6H_5N_2OH \longrightarrow \begin{array}{l}R—C=O\\ \quad\;|\\ \quad\;CH—N=N—C_6H_5\\ \quad\;|\\ R—C=O\end{array} \longrightarrow \begin{array}{l}R—C=O\\ \quad\;|\\ \quad\;C=N—NHC_6H_5.\\ \quad\;|\\ R—C=O\end{array}$$

$$C_6H_5OH + C_6H_5N_2OH \longrightarrow HOC_6H_4—N=N—C_6H_5.$$

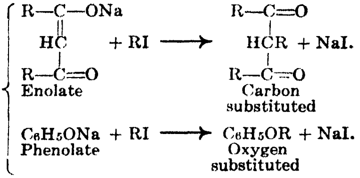
II



$$\begin{array}{l}R—C=O\\ \quad\;|\\ \quad\;CH_2\\ \quad\;|\\ R—C=O\end{array} + HONO \longrightarrow \begin{array}{l}R—C=O\\ \quad\;|\\ HC—NO\\ \quad\;|\\ R—C=O\end{array} \longrightarrow \begin{array}{l}R—C=O\\ \quad\;|\\ \quad\;C=NOH.\\ \quad\;|\\ R—C=O\end{array}$$

$$C_6H_5OH + HONO \longrightarrow HOC_6H_4—NO \xrightarrow{NaOH} O=C_6H_4=NONa.$$

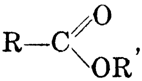
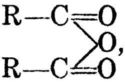
III



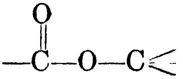
$$\begin{array}{l}R—C—ONa\\ \quad\;\|\\ \;HC\\ \quad\;|\\ R—C=O\end{array} + RI \longrightarrow \begin{array}{l}R—C=O\\ \quad\;|\\ HCR\\ \quad\;|\\ R—C=O\end{array} + NaI.$$

$$C_6H_5ONa + RI \longrightarrow C_6H_5OR + NaI.$$

TEST 3. ESTERS, ACID ANHYDRIDES, AND LACTONES

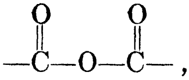
Esters,  $R—C\begin{array}{l}{}^{\diagup\!\!\!\diagup O}\\ {}_{\diagdown OR}\end{array}$, and acid anhydrides,  $\begin{array}{l}R—C=O\\ \qquad\;\;\rangle O\\ R—C=O\end{array}$, can be hydrolyzed to acids. The reactions differ in that the esters hydrolyze to acids and alcohols, whereas the acid anhydrides yield only acids. Further, the hydrolysis of an acid anhydride is generally a much more rapid reaction than is that of an ester. When the reaction is very fast at room temperature and in almost neutral solution, it will occur to an appreciable extent during titration, and the substance will respond to Test 1 and so appear to be an acid. This is generally the case with acid anhydrides, but it is a rare phenomenon with the esters.

If the characteristic groups,



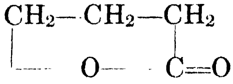
$$-\overset{\overset{\displaystyle O}{\|}}{C}-O-C\!<$$

and

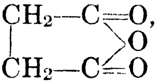


$$-\overset{\overset{\displaystyle O}{\|}}{C}-O-\overset{\overset{\displaystyle O}{\|}}{C}-,$$

form part of a ring, as in



and



the substances are called lactones and internal acid anhydrides respectively. The former hydrolyze to hydroxy acids and the latter to dibasic acids.

The basis of Tests 3a and 3b is the hydrolysis of compounds to form acids. Hydrolysis proceeds more rapidly in alkaline than in neutral solutions, and generally it is faster with an alcoholic than with an aqueous solution of sodium hydroxide (probably on account of the greater solubility of the ester in alcohol). Consequently, in Test 3a an alcoholic solution of sodium hydroxide is used, but in 3b, since a search for the alcohol formed by hydrolysis is to be made, an alcoholic solution cannot be used. In Test 3a the formation of acid is determined by using a known amount of alkali and determining how much of it is used up by titrating the excess of alkali left after the reaction has taken place. Since some reaction may occur between the alkali and the glass, a tube containing nothing but the alcohol and alkali is heated in a similar manner, so that it will serve as a blank experiment.

Carbonic acid may be one of the acids formed by hydrolysis. It can be distinguished from the other acids by comparing the results of titrations at room temperatures and at 100°. Carbonic acid behaves as a monobasic acid when titrated in the cold with phenolphthalein as an indicator, as shown by the equation

$$H_2CO_3 + OH^- \rightleftarrows HCO_3^- + H_2O.$$

If, when the end point is reached, the solution is heated, carbon dioxide is volatilized, and the reaction represented by the equation is reversed. The hydroxide ion produced reacts with the bicarbonate ion so that the net change on heating is the evolution of half the carbon dioxide:

$$2\ HCO_3^- \xrightarrow{\text{Heat}} CO_3^{--} + CO_2 + H_2O.$$

A solution containing carbonate ion is alkaline to phenolphthalein, so that, on heating, the pink color of the indicator returns. If at this point the titration with acid is continued, the carbonate ion is again converted to bicarbonate ion, which in turn undergoes the above reaction on continued heating. The pink color of the indicator will then persist until all the carbonic acid is driven out *if the solution is maintained at the boiling point.* Other organic acids are not volatile under these conditions,* for in solutions that are alkaline or neutral to phenolphthalein they are present, not as free acids, but as salts. The additional acid required beyond the end point at room temperature corresponds to the mols of carbon dioxide evolved.

Strictly speaking, the procedure under Test 3b is not a test. It is an outline of methods used in isolating products of hydrolysis.

In some cases carbon-to-carbon bonds may be hydrolyzed to give acids under the conditions of these tests. This is especially likely to occur in substances having the structures of 1, 3 diketones and β-ketonic acids, as, for instance, the following enols:

$$CH_3{-}CO{-}CH_2{-}CO{-}CH_3 \quad \text{and} \quad CH_3{-}CO{-}CH_2{-}COOH.$$

In the majority of these cases the presence of such groups will already have been shown by Test 2.

Test 3a. From a pipette or burette introduce 2 cc. of a 1.0 *N* solution of sodium hydroxide in alcohol into each of two strong glass tubes (about 12 mm. in diameter and 20 cm. long). To one add a weighed amount of the unknown (about 0.1 g.). Seal both tubes. Heat them for an hour at 100°. Cool and open the tubes and wash the contents into separate beakers with distilled water, with the usual precautions observed in quantitative work. Titrate each solution with decinormal acid in the cold, using phenolphthalein as an indicator. Then heat each to boiling, and if the pink color reappears add standard acid until on further heating it does not reappear. The acid added after heating represents carbonic acid according to the equation

---

* Malonic acid and some ketonic acids, as acetoacetic acid, slowly lose carbon dioxide when an acid solution containing them is boiled.

$$HCO_3^- + H^+ \longrightarrow CO_2 + H_2O.$$

The calculation of the results is based on the fact that any acid produced by hydrolysis neutralizes some of the alkali. The amount neutralized is given by the difference in the amount of acid needed, at room temperature, to titrate the blank and the amount needed to titrate the contents of the tube containing the sample. The actual amount of alkali originally introduced into the two tubes need not be known accurately and is of no significance, provided each tube received the same amount. If the substance acted as an acid in Test 1, it will of course neutralize alkali in this test also. The number of equivalents of alkali used up equals the number of equivalents of acid produced in the tube, so that the equivalent weight of the substance may be calculated:

$$\text{Equivalent weight} = \frac{\text{weight of sample}}{\text{number of equivalents}}.$$

If the equivalent weight of the substance upon direct titration (Test 1a) was very high, then an equivalent weight of less than 500 in this test shows that the unknown is an ester, a lactone, or an acid anhydride. Should the equivalent weights as determined by the two procedures agree, the result obtained in this test is merely confirmatory of that previously obtained. When an acidic substance neutralizes more alkali in Test 3a than in Test 1a, and both results are quantitatively correct, there should be a simple ratio between the equivalent weights as determined in the two cases. This will be the case if the substance is both an acid and an ester.

No quantitative significance can be attached to the numerical value of the equivalent weight unless concordant results have been obtained in duplicate experiments in which the time of hydrolysis has been varied. A very high equivalent weight suggests incomplete hydrolysis.

The presence of carbonate ion as a product of hydrolysis indicates that the substance is an ester of carbonic acid or of an acid which readily loses carbonic acid under the conditions of the experiment. If the total acid produced as indicated by the cold titration is greater than the amount of carbonic acid as shown by the difference in the hot and cold titrations, some other acid, in addition to carbonic, must have been formed. Since the alkali may contain carbonate, or since carbonate may be dissolved from the glass on heating, the blank must be titrated hot, and if any carbonate is found, a corresponding correction must be applied to the sample.

The procedure for Tests 1 and 3 may be shortened by dissolving the weighed sample of the unknown in the bomb tube in alcohol and titrating with standard 1.0 *N* aqueous alkali, using phenolphthalein as an indicator. After the end point is reached, add a known excess of alkali, seal the tube, and proceed as above. The usual blank experiment should be performed, using a tube containing the same excess of alkali. This procedure is particularly useful in examining impure products of esterification such as those formed in Test 6b, since it eliminates any correction for traces of free acid in the sample. The numerical value of the equivalent weight as calculated may be of no significance, owing to impurities, but qualitatively the presence of a hydrolyzable derivative of an acid may be detected.

Test 3b. In a flask fitted with a good reflux condenser boil 5 g. of the substance with 100 cc. of 1.0 *N* sodium hydroxide. The alkali should be free from carbonate, and the exact amount of acid required to neutralize it should be known. It may require two hours or more to complete the hydrolysis. In boiling an alkaline solution there is danger of bumping. The trouble is prevented by placing in the flask capillary tubes that are sealed 1 or 2 cm. from the lower ends. Complete solution usually indicates complete hydrolysis. The disappearance of a characteristic odor also indicates the completion of the reaction. In case of excessively slow hydrolysis alcoholic alkali may be used, in which case the detection of low-boiling alcohols as products of hydrolysis is difficult.

After hydrolysis distill about 50 cc. of the mixture. Boil the distillate in a small flask fitted with a tall fractionating column. Place the thermometer bulb several inches below the side arm and boil the solution for some time with refluxing but without distilling. Keep the bulb of the thermometer completely surrounded by the vapor. This condition is maintained until the thermometer reading is practically constant, and then distillation is allowed to proceed slowly. With the lag in the thermometer eliminated in this way, the presence of a small amount of a low-boiling substance can be detected. A turbidity in the fractionating column or oily drops in the condenser indicate the presence of a relatively insoluble alcohol. In dealing with the more soluble alcohols (lower members of the series) two phases may not appear. Continue the fractionation as long as oily drops appear, or, in the absence of that phenomenon, until the temperature begins to rise rapidly. If the thermometer fails to indicate a definite change in the rate of elevation of temperature, continue the fractionation until the boiling point reaches 99°. Salt out the alcohol from the distillate by saturating the latter with potassium carbonate, and after pipetting off the alcohol dry it by refluxing it for ten or fifteen minutes over calcium oxide, and determine its boiling point.

The alkaline residue from the first distillation contains the acid produced by hydrolysis. Acidify it with an amount of 1.0 *N* nitric acid equivalent to the alkali used. Any precipitate is probably an insoluble acid. It should be filtered off. If no precipitate appears, steam-distill the solution. If the first distillate is acid to litmus, distill over about 125 cc. and titrate a 10-cubic-centimeter portion with 0.1 *N* sodium hydroxide, using phenolphthalein as the indicator. Using the result of this titration, dilute the whole or part of the remaining distillate with enough water to obtain 125 cc. of a solution of the acid of a normality between 0.5 and 0.1 *N*. Determine its exact normality by titrating a 10-cubic-centimeter portion with 0.1 *N* sodium hydroxide, using phenolphthalein as an indicator. Distill 100 cc. of the solution in a 250-cubic-centimeter distilling flask, allowing as little fractionation as possible. Collect separately, in small, dry graduated cylinders,[*] the first two 10-cubic-centimeter portions of distillate, and titrate each of them with 0.1 *N* sodium hydroxide, using phenolphthalein as the indicator. From the results of these titrations calculate the fractions of the acid in the 100-cubic-centimeter sample that distilled over in the first and second 10-cubic-centimeter portions, and interpret the result with reference to the table[†] on the opposite page.

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[*] Suitable graduated cylinders can be made from test tubes by measuring into the tubes 10-cubic-centimeter portions of water with the aid of a burette or pipette and marking the tubes at the water levels.

[†] The percentage amounts of the acid which distill with the various 10-cubic-centimeter portions are known as the Duclaux constants for that acid (*Ann. chim. phys.* [5], **2**, 289 (1874); *J. Am. Chem. Soc.*, **39**, 731, 746 (1917)). The numerical results are within the above limits for wide ranges of concentration, if the specified amount of solution and size of flask are used in a continuous distillation. It is interesting to observe that the higher-boiling acids are the more volatile from aqueous

DISTILLATION OF 100 CUBIC CENTIMETERS OF DILUTE AQUEOUS SOLUTION OF A FATTY ACID

	PER CENT OF ACID IN 10 CUBIC CENTIMETERS OF DISTILLATE			
	Formic Acid	Acetic Acid	Propionic Acid	Higher Fatty Acid
First 10 cc.	3.5–4.5%	6.5–7.5%	11–12%	More than 12%
Second 10 cc.	More than in first portion	Slightly more than in first portion	Slightly less than in first portion	Markedly less than in first portion

If one of the higher fatty acids is indicated by this test, collect all portions of the solution and add enough mineral acid to neutralize the alkali used in the various titrations. Distill the mixture, using a good fractionating column, and collect 30 cc. of the distillate, which will contain nearly all the fatty acid. Dissolve about 8 g. of calcium chloride in this distillate and extract the solution with ether, using two 10-cubic-centimeter portions of ether for the extraction. Mix the two ether extracts and dry the mixture with fused calcium chloride. Decant off the ether solution and fractionally distill it from a small distilling flask. The high-boiling fraction will be the fatty acid. It may be identified by its boiling point or by the physical constants of an anilide (see page 78) or other derivative prepared from it.

If there is neither an insoluble nor a volatile acid, neutralize the solution and precipitate the soluble, nonvolatile acid as the mercurous salt (lead ion or silver ion may be used instead of mercurous ion). Wash the precipitate and suspend it in water. Decompose it with hydrogen sulphide, filter off the metallic sulphide, evaporate the filtrate, and identify the acid by its melting point and other physical properties.

If no precipitate should be formed with mercurous ion, acidify the solution and extract it with ether, dry the ether with sodium sulphate, and evaporate it. This last treatment is necessary for lactic acid.

If no product other than an acid has been identified up to this point, the unknown may be an acid anhydride, a lactone, or an ester containing a soluble nonvolatile alcohol. Refer to Test 1b for a method of determining from the acid produced by hydrolysis whether the unknown is an acid anhydride or a lactone. If it is neither of these, remove the acid (and any heavy metal as sulphide),

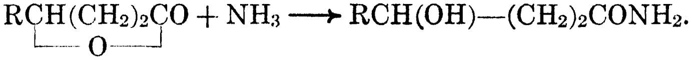
solution. The reason for this is made evident by a study of the composition-boiling-point diagrams for these binary mixtures, or by a qualitative consideration of the types of deviation from Raoult's law to be expected.

neutralize the solution, and remove the water from it by evaporation on a steam bath. Extract the residue with a mixture of alcohol and ether. Boil off the alcohol and ether and make the sirupy residue into a paste with powdered potassium acid sulphate. Heat the mixture in a tube until frothing ceases, and collect the vapors in water. Test the water solution of the vapor for an aldehyde with fuchsin decolorized with sulphur dioxide. A red or blue color shows the presence of an aldehyde derived from the alcohol in the ester. Allow the solution to stand overnight; a blue or violet color indicates acrolein, and hence that the alcohol is glycerine. The acrolein in this test may also be recognized by its odor.

Esters, acid anhydrides, and lactones form amides when treated with an aqueous or alcoholic solution of ammonia:

$$RCOOR + NH_3 \longrightarrow RCONH_2 + ROH.$$

$$(RCO)_2O + 2\ NH_3 \longrightarrow RCONH_2 + RCO_2NH_4.$$



$$RCH(CH_2)_2CO + NH_3 \longrightarrow RCH(OH)\text{—}(CH_2)_2CONH_2.$$

The amides are usually solids and serve as convenient derivatives for the identification of the acids.

The three classes of compounds react with the Grignard reagent to form ketones and alcohols. Esters condense in the presence of sodium ethylate to give β-ketonic esters (acetoacetic ester condensation). Hydroxamic acids and hydrazides are formed from hydroxylamines and hydrazines respectively. Reduction may be carried out by sodium amalgam in acetic acid solution, or by hydrogen gas in the presence of a suitable catalyst (platinum black, palladium oxide) to give aldehydes or alcohols. None of these reactions is as characteristic of these classes of compounds as is the reaction of hydrolysis to form acids.

TEST 4. ALDEHYDES, KETONES, AND ACETALS

Every aldehyde and ketone contains a carbonyl, or $>C=O$ group. Of the two groups attached to the carbonyl of an aldehyde one is always a hydrogen, while in a ketone both are carbon residues. The aldehyde group should then be represented as —CHO. The carbonyl groups of aldehydes generally react more rapidly than do those of ketones. Although the two types of compounds may give the same reactions if only the carbonyl is considered, they differ in rate of reaction and in the fact that an aldehyde is readily oxidized to an acid by certain reagents, while a ketone is not readily oxidized by the same reagents. The basis of Test 4 is a general test for the carbonyl followed by a specific test for an aldehyde.

A number of reagents react with carbonyl groups, any one of which could possibly be used to detect the existence of the group in a given substance. The following is a partial list of such reagents:

REAGENT	PRODUCT
Hydroxylamine	Oxime
Substituted hydrazine	Hydrazone
Hydrogen cyanide	Cyanhydrin
Grignard reagent	Higher alcohol

Of the four reagents the first two are the most useful. Even with these, wide differences are found in the rates at which different carbonyl derivatives react with the specific reagents. For instance, anthraquinone and camphor form oximes very slowly even on long heating at high temperatures with hydroxylamine. Some hydrazines are reported to react with aldehydes but not with ketones. Oximes and hydrazones of aldehydes and methyl ketones are formed faster than are those of the higher ketones.

Hydrazone formation is usually detected by observing the formation of a precipitate when the aldehyde or ketone and a hydrazine are dissolved in dilute acetic acid and the solution is warmed. Hydrazines are used which yield sparingly soluble hydrazones, such as phenylhydrazine, $C_6H_5—NH—NH_2$, *p*-nitrophenylhydrazine, $p\text{-}NO_2—C_6H_4—NH—NH_2$, and semicarbazide, $NH_2—CO—NH—NH_2$. The above criterion of the reaction is usually valid if the substance treated under the same conditions, but without the hydrazine, does not give a precipitate. It is usually safer to examine the product of the reaction and prove that it is a hydrazone. This involves hydrolyzing the hydrazone to the hydrazine,

$$R_2C{=}N—NH—C_6H_5 \xrightarrow[H_2O]{H^+} R_2CO + C_6H_5—NH—NH_2,$$

and testing for the latter with Tollen's reagent.* Some hydrazones are slow to form and difficult to hydrolyze, so that as a rule the oxime is the preferable derivative to prepare.

In detecting the formation of an oxime after treatment with hydroxylamine, advantage is taken of its tendency to form soluble salts with acids and bases:

$$R_2C{=}NOH + OH^- \rightleftarrows R_2C{=}NO^- + H_2O,$$
$$R_2C{=}NOH + H^+ \rightleftarrows R_2C{=}NHOH^+.$$

Oximes that are sparingly soluble in water may be appreciably soluble in dilute alkalies or acids. The formation of a metallic salt is best detected by neutralizing a clear alkaline solution and noting the precipitation of the more sparingly soluble oxime. If the proper blank experiments are made in the absence of hydroxylamine without the formation of such a precipitate, it may be concluded that an oxime has been formed. The increase in solubility due to salt formation may be very slight, since the oximes are very weak acids or bases, so that in many cases the criterion fails. Moreover, many oximes are soluble in water, so that no precipitate is formed upon neutralizing the solution.

Oxime formation may also be detected by hydrolysis of the oxime to hydroxylamine after separation of the oxime from excess hydroxylamine by ether extraction:

$$R_2C{=}NOH + H_2O \xrightarrow{H^+} R_2CO + H_2NOH.$$

The presence of H_2NOH as one product of hydrolysis may be detected by Tollen's reagent, provided that the other product of hydrolysis either does not reduce Tollen's reagent or may be separated completely from the hydroxylamine salt by filtration or by evaporation of the solution to dryness on a steam bath. The salts of hydroxylamine are stable and nonvolatile, whereas most aldehydes and ketones are relatively low boiling and evaporate with the water.

A different procedure for the detection of oxime formation is necessary if the oxime is very soluble in water and difficult to extract with ether. The isolation of the oxime in this case is avoided and its presence made evident by first decomposing* any excess hydroxylamine by heating the alkaline solution and then regenerating hydroxylamine by hydrolyzing any oxime present with acid. The disappearance of the excess hydroxylamine and the subsequent formation of hydroxylamine salt as a hydrolysis product are detected by a specific test which depends upon the formation of benzhydroxamic acid (see Division II, Test 4, for the reaction concerned). The success of this procedure depends upon the fact that the rate of decomposition of free hydroxylamine is slow with respect to that of oxime formation but rapid as compared with that of oxime hydrolysis. Consequently a condition will be reached upon heating the alkaline mixture of carbonyl derivative and hydroxylamine in which the ratio of free hydroxylamine to oxime is very small. It follows, therefore, that prolonged heating of the mixture will destroy both free hydroxylamine and the oxime, and is to be avoided. These three methods of detecting oxime formation are outlined in Tests 4a, 4b, and 4c, the last of which is particularly applicable in such cases as formaldehyde and semiacetal sugars.

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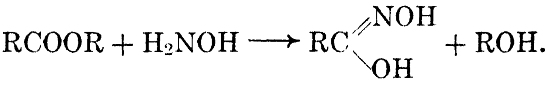
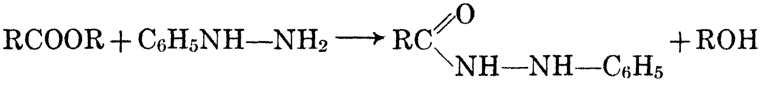
* The oxidation of an aryl hydrazine may give rise to aromatic hydrocarbons, phenols, elementary nitrogen, diazo compounds, and tetrazones. The result depends upon the oxidizing agent used and upon the conditions of the experiment.

Esters presumably possess a carbonyl group. They react with hydroxylamine and with hydrazines to form hydroxamic acids and hydrazides respectively:



$$\mathrm{RCOOR} + \mathrm{H_2NOH} \longrightarrow \mathrm{RC}\left\langle\begin{matrix}\mathrm{NOH}\\ \mathrm{OH}\end{matrix}\right. + \mathrm{ROH}.$$



$$\mathrm{RCOOR} + \mathrm{C_6H_5NH{-}NH_2} \longrightarrow \mathrm{RC}\left\langle\begin{matrix}\mathrm{O}\\ \mathrm{NH{-}NH{-}C_6H_5}\end{matrix}\right. + \mathrm{ROH}$$

These reactions may be looked upon either as ammonolyses of esters or as first an addition of the reagent to the carbonyl of the ester, followed by loss of alcohol. Normally the presence of an ester will have been previously determined.

Acetals and polymerized aldehydes must be converted into the simple aldehydes before they are treated with hydroxylamine. Heating with dilute aqueous acid accomplishes this, as the reaction is essentially one of hydrolysis of an ether. Hydroxyl ion does not catalyze the hydrolysis of ethers and acetals, so that in an alkaline medium an acetal does not readily give the aldehyde reactions, whereas in an acid medium (Schiff's reagent) hydrolysis may be sufficiently rapid to cause the acetal to react as an aldehyde:

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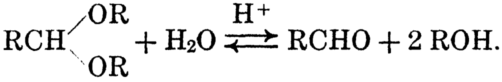
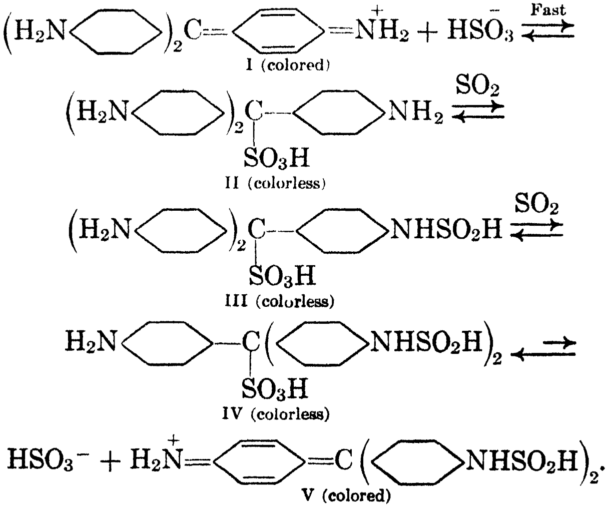
* Hydroxylamine oxidizes and reduces itself when heated in alkaline aqueous solution to form ammonia, nitrogen, and nitrous oxide.



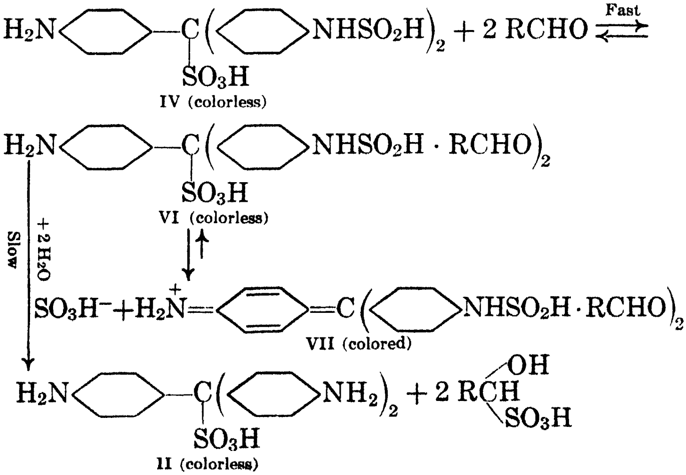
$$RCH(OR)_2 + H_2O \overset{H^+}{\rightleftarrows} RCHO + 2\,ROH.$$

If the result of Test 4a or 4b or 4c indicates the presence of a carbonyl group, the substance is tested for an aldehyde group. A negative test for the aldehyde group places the substance as a ketone. Schiff's reagent is made by decolorizing magenta with sulphur dioxide. The reaction between fuchsin and sulphurous acid is reversible and may be represented as follows:



Whether or not color is produced in triphenylmethane derivatives depends upon the tendency of the negative group on the methane carbon to ionize. Halogens tend to ionize more than do OH or SO_3H groups; the ionization of a given negative group may be effected by solvents and by substituents in the phenyl groups. The ion so produced is colored. The equilibria above favor the colorless un-ionized forms, of which compound II has been isolated as a hydrate. Compounds III and IV are present in appreciable quantities when the hydrogen ion concentration is low and excess sulphurous acid is present. They may be said to represent the main constituents of Schiff's reagent.

The colored substance formed when an aldehyde is added to Schiff's reagent is derived from an addition product between compound IV and the aldehyde. This conclusion is indicated by the following facts. The color produced in the test by the aldehyde has a bluish tinge not present in the original, I, so that the reaction is not simply the removal of SO_2. Fuchsin itself reacts very slowly with aldehydes to produce a color different from that formed in the presence of SO_2. Compound II does not give a color with aldehydes, but does so after SO_2 has first been added to it. If aldehyde and SO_2 are allowed to react to form aldehyde sulphurous acid ($R-CHOH-SO_3H$) before being added to III, no color is produced. Similarly, acetals, semiacetals, and chloral hydrate give no test. On standing, the color of the solution gradually fades. These facts suggest that the aldehyde reacts rapidly with the amine sulphinic acids (faster than with H_2SO_3), thereby changing the substituent in the phenyl nucleus and hence affecting the ionization of the compound.



IV (colorless)

VI (colorless)

VII (colored)

II (colorless)

The formula VII above, suggested by Wieland and Scheuing,* is based on evidence that when two amino groups have reacted with sulphurous acid and aldehyde, the resulting compound ionizes the SO_3H from the methane carbon atom more than does the mono-substituted derivative, producing the colored form. Any process which removes SO_2 will produce a color with Schiff's reagent, such as heating, or treatment with alkali, or with salts of weak acids. The lower ketones may react slowly, so that a maximum time limit is set for the test.

The aromatic aldehydes, such as benzaldehyde, react more slowly than do the aliphatic aldehydes, so that the reagent should be tested by the use of benzaldehyde. If the reagent is very sensitive (if the color comes quickly with benzaldehyde), mere traces of aldehyde in alcohols or ketones may give the test. Only one or two drops of a pure substance should therefore be used for 10 cc. of the reagent. Acetals react slowly as the acid present in Schiff's reagent catalyzes their hydrolysis to aldehydes.

The reduction of Tollen's reagent serves as a confirmatory test for the aldehyde group. The main reaction is

$$RCHO + 2\,Ag^+ + 3\,OH^- \longrightarrow RCO_2^- + 2\,Ag + 2\,H_2O.$$

Tollen's reagent contains silver nitrate, ammonia, and sodium hydroxide. The last reagent hastens the reaction; a high concentration of it, in fact, makes the reagent too sensitive, so that any organic matter is apt to reduce the silver ion. Here again the time for the reaction must be controlled to distinguish aldehydes from other oxidizable compounds. While this is called the "silver mirror test," no mirror is formed if the glass is not clean nor if the reaction is too fast. A dark precipitate, insoluble in ammonia, is the usual result of the test.

Test 4a. Heat together 1 part of the unknown, 1 part of hydroxylamine hydrochloride, 1 part of solid sodium hydroxide, and 5 parts of 80 per cent alcohol for ten minutes at 100°. Cool the mixture and dilute it with 4 volumes of water, shake it, and allow it to stand for a few minutes. Filter the mixture until a clear solution is obtained, and exactly neutralize the filtrate with 6 *N* acid. A precipitate or turbidity indicates the formation of an oxime. With this experiment a blank should be run in which no hydroxylamine is used. This test may be made with small quantities and is of value chiefly with aldehydes and ketones which are themselves sparingly soluble in water, since the oximes of the lower aldehydes and ketones are soluble.

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* *Ber.*, **54**, 2527 (1921).

Test 4b. If Test 4a is negative, repeat as before, using larger quantities (from 1 to 2 g.), and heat for half an hour. Then neutralize the solution and extract it with ether. Wash the ethereal extract with dilute acid, dry it with sodium sulphate, and boil off the ether. The formation of a new compound which gives the test for oximes (see Test 4a, Division II) indicates the presence of a ketone or an aldehyde.

Test 4c. If Tests 4a and 4b have given negative results, heat together upon the steam bath 0.5 g. of the unknown, 0.5 g. of hydroxylamine hydrochloride, 1.0 g. of solid sodium hydroxide, and about 25 cc. of water. If the unknown is volatile, use a reflux condenser to prevent evaporation of the substance. After fifteen minutes test a 1-cubic-centimeter portion of the aqueous solution for unchanged hydroxylamine by adding to it a drop of benzoyl chloride, warming the mixture for a few minutes, and then adding a few drops of ferric chloride solution and a similar amount of 6 *N* hydrochloric acid. A reddish violet coloration indicates the presence of free hydroxylamine. Continue the heating of the mixture, with occasional testing, until no test for hydroxylamine is obtained; then add 5 cc. of 12 *N* hydrochloric acid and heat the solution for half an hour. Again test a portion of the aqueous solution for hydroxylamine as before, except that the acidified solution is made alkaline by the addition of sodium carbonate solution before adding the benzoyl chloride. If hydroxylamine appears after acidic hydrolysis, an oxime has been formed, and hence a carbonyl group is present in the unknown.

Test 4d. If 4a, 4b, or 4c is positive, shake 0.1 g. of the unknown with 10 cc. of magenta solution decolorized with sulphur dioxide (Schiff's reagent) for two minutes. A distinct color, from red to blue, indicates an aldehyde. The reagent should contain 0.1 g. of rosaniline decolorized with 5 cc. of saturated sulphur dioxide solution in 100 cc. of water. Its sensitiveness should be tested before use, by applying the test to an aromatic aldehyde. If not sufficiently sensitive, treat a portion of it with sodium acetate solution until a pink color appears, and then decolorize it with some more of the insensitive reagent. This test is given by aldehydes and most acetals and polymerized aldehydes. Traces of aldehydes in other compounds also respond to this test, and a trace of a more reactive aldehyde may be mistaken for a slower acting aldehyde. In the case of a slight colorization or very slow reaction the student should reconsider his decision, repurify the sample,* and repeat the test.

A positive test with Schiff's reagent should be confirmed by adding 0.1 g. to 10 cc. of Tollen's reagent in the cold. The appearance of a silver mirror or fine gray precipitate within one minute indicates an aldehyde.

Test 4e. If Tests 4a, 4b, and 4c are negative, boil 0.1 g. of the substance a few minutes with 5 cc. of 1 *N* hydrochloric acid, cool the solution and neutralize it. Repeat Test 4d with this solution. A distinct color with Schiff's reagent indicates the presence of an acetal or a polymerized aldehyde. The preliminary heating with acid hydrolyzes acetals and depolymerizes most polymerized aldehydes. Long heating of primary glycols with strong acid may produce aldehydes according to the equation

$$\mathrm{RCHOH{-}CH_2OH \longrightarrow RCH_2{-}CHO + H_2O.}$$

A positive test with Schiff's reagent should be confirmed with Tollen's reagent as in Test 4d.

Other reactions besides oxime and hydrazone formation involve the carbonyl group and are sometimes cited as characteristic reactions of compounds containing that group. Some of these are mentioned in the following paragraphs.

The aldol condensation occurs with both aldehydes and ketones. It is catalyzed by dilute alkalies and acids.

$$\mathrm{R{-}CH_2{-}CO{-}R + R{-}CH_2{-}CO{-}R \rightleftharpoons R{-}CH_2{-}C(OH)R{-}CHR{-}CO{-}R.}$$

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* If conclusive results cannot be obtained after ordinary methods of purification have been applied, shake a 1-gram sample, dissolved in benzene, with an excess of Tollen's reagent for about two minutes. Remove the benzene layer, wash it with water to remove the ammonia, and test portions of the solution with Schiff's and Tollen's reagents both before and after subjecting the samples to acid hydrolysis. The preliminary treatment with Tollen's reagent will remove any aldehyde and permit the detection of aldehyde which may be produced by hydrolysis or depolymerization.

The reaction * is reversible, and the equilibrium has been measured in a few cases. Since there is no easy way of proving that any reaction which has occurred is specifically the aldol condensation, and since aldehydes and ketones which have no hydrogen upon the α-carbon atom do not condense in this way, the reaction is not suitable as the basis of a test for the carbonyl group.

The benzoin condensation and the Cannizzaro reaction take place only with those aldehydes which do not undergo the aldol condensation.

$$2\ C_6H_5\text{—}CHO \xrightarrow{CN^-} \underset{\text{Benzoin}}{C_6H_5\text{—}CH(OH)\text{—}CO\text{—}C_6H_5}.$$

$$2\ C_6H_5\text{—}CHO \xrightarrow{OH^-} \underset{\text{Benzyl benzoate}}{C_6H_5\text{—}CO\text{—}O\text{—}CH_2\text{—}C_6H_5}.$$

The addition of sodium bisulphite to an aldehyde or ketone is reversible. The addition does not usually occur with the higher ketones, and the product is often difficult to purify and identify. The reaction may be written

$$R\text{—}CHO + NaHSO_3 \longrightarrow R\text{—}CH(OH)\text{—}SO_3Na.$$

The addition of ammonia is usually accompanied by the aldol condensation or by polymerization. Products having the composition of addition products have been isolated in the case of some aldehydes, but formaldehyde, benzaldehyde, and ketones in general do not give simple products. The product under the best conditions resinifies readily and cannot be easily identified except in a few cases. The reaction for acetaldehyde should be written

$$3\ CH_3\text{—}CHO + 3\ NH_3 \longrightarrow (CH_3\text{—}CH(OH)NH_2)_3.$$

Acetal formation is not a general reaction in the case of ketones, and the product in the case of aldehydes is difficult to isolate and identify on a small scale. Similarly, the

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* The β-hydroxy aldehydes and ketones formed by the aldol type of condensation lose water to form ethylene derivatives more readily than do ordinary alcohols. Hence the condensation, particularly in the case of ketones, is often followed by a reaction of the type

$$R\text{—}CH_2\text{—}C(OH)R\text{—}CHR\text{—}CO\text{—}R \longrightarrow RCH_2\text{—}CR{=}CR\text{—}CO\text{—}R + H_2O.$$

polymerization of aldehydes cannot readily be detected independently of other tests for the aldehyde group. Resinification of aldehydes (that is, the formation of a yellow or brown color on warming with concentrated sodium hydroxide) is readily detected, but aromatic aldehydes do not give resins. Formaldehyde does not form a resinous material.

Oxidation and reduction reactions which depend for detection upon the isolation of the product formed, such as the acid from an aldehyde, the alcohol from an aldehyde or ketone, lower acids from ketones, and pinacols (glycols) from aldehydes and ketones, are difficult and tedious to apply. Similarly, the replacement of the oxygen of the carbonyl group by halogens through the use of phosphoric halides cannot be detected except by identification of the product.

The addition of hydrogen cyanide takes place readily in the case of most aldehydes and ketones. The reaction is reversible. In order to detect whether the reaction has taken place it is necessary to isolate the cyanhydrin. The cyanhydrin may in turn be hydrolyzed to a hydroxy acid, and the two reactions are used to establish the position rather than the presence of the carbonyl group, through the identification of the hydroxy acid.

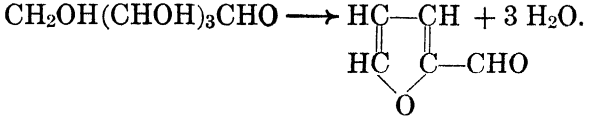
The Grignard reagent, particularly the methyl derivative, could be used to detect the carbonyl group in aldehydes, ketones, and esters, in the absence of acids, alcohols, phenols, nitriles, amides, imides, and halogen derivatives. A standard solution of CH_3MgI in ether would be added to the unknown in dry ether. After the solution has been warmed for a short time, acidified water would be added and the excess CH_3MgI converted into methane by the reaction

$$CH_3MgI + H_2O \longrightarrow CH_4 + MgOHI.$$

The amount of methane liberated would be compared with the amount liberated from the same volume of reagent but without the unknown present. Any appreciable difference in the two volumes of methane would indicate that some of the Grignard reagent had reacted, presumably with a carbonyl group.

TEST 5. CARBOHYDRATES AND GLUCOSIDES

An aldehyde, furfural, is readily formed from pentoses upon heating with concentrated acids:



It may be formed in smaller quantities from other carbohydrates, together with compounds of a similar nature, such as hydroxymethylfurfural, from hexoses.* Furfural and its derivatives condense with aromatic amines and phenols to form colored substances, the exact structures of which are unknown. The reaction probably involves a condensation of the aldehyde group with the amine or hydroxyl, or possibly with the ring. We know that reactions of this type occur with benzaldehyde.

$$C_6H_5CHO + C_6H_5NH_2 \longrightarrow C_6H_5CH{=}NC_6H_5 + H_2O,$$
$$C_6H_5CHO + 2\ C_6H_5OH \longrightarrow C_6H_5CH(C_6H_4OH)_2 + H_2O.$$

Test 5 is the Molisch test for carbohydrates, in which the carbohydrate is subjected to the action of concentrated sulphuric acid in the presence of a phenol. Under these conditions it is assumed that a furfural derivative is formed which reacts with the phenol to form a colored substance. The fundamental reactions involved are presumably similar to those outlined above. In specific instances it is probable that other changes also occur.†

A monosaccharide does not react as if it had a free carbonyl group. The evidence of mutarotation and the formation of α

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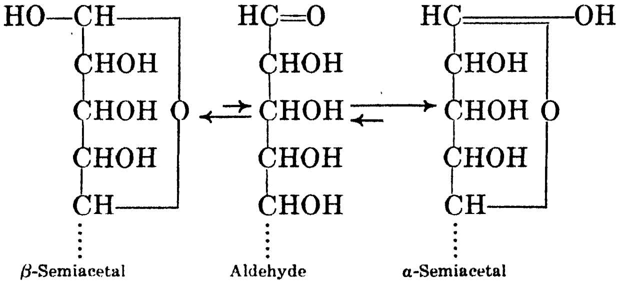
* *Chem. Abs.*, **4**, 3222; **13**, 2347.

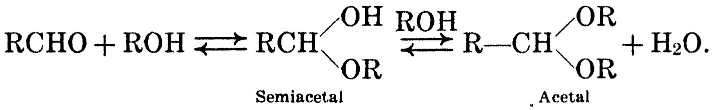
† H. Schiff, *Centralblatt* [3], **18**, 904 (1887). Balling and Aldinger, *J. prakt. Chem.*, **100**, 86 (1919), or *Chem. Abs.*, **14**, 3638 (1920), give the formula of the condensation product between furfural and aromatic primary amines as that of a derivative of hydroxyglutaconaldehyde:

$$2\ o\text{-}NO_2\text{—}C_6H_4\text{—}NH_2 + C_4H_3O\text{—}CHO \longrightarrow$$
$$o\text{-}NO_2\text{—}C_6H_4\text{—}NH\text{—}CH{=}CH\text{—}CH{=}C(OH)\text{—}CH{=}N\text{—}C_6H_4\text{—}NO_2 + H_2O$$

and β glucosides point to an equilibrium which may be expressed by the formulas below. The question as to which hydroxyl group of the sugar is involved in the semiacetal formation is not definitely settled. See *J. Chem. Soc.*, **123**, 898 (1923); **129**, 89 (1926).



This equilibrium is analogous to



$$RCHO + ROH \rightleftarrows RCH\begin{cases}OH\\OR\end{cases} \overset{ROH}{\rightleftarrows} R{-}CH\begin{cases}OR\\OR\end{cases} + H_2O.$$

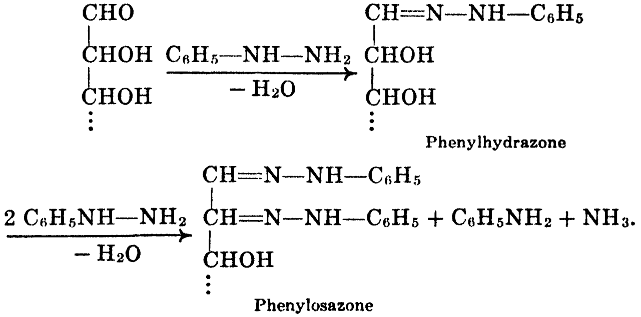
Semiacetal Acetal

In the monosaccharides the equilibrium lies in favor of the semiacetal (lactone) form, while the opposite is true of ordinary aldehydes and ketones. The semiacetal of the sugar may form a complete acetal by reacting with another alcohol. In the case of glucose such a compound is called a glucoside. This second alcohol may be of any type, even another monosaccharide. In this way the disaccharides and polysaccharides are built up. Keto sugars are found as internal semiacetals (lactones) and as complete acetals in some disaccharides, as, for instance, fructose in cane sugar.

The equilibria between aldehydes, alcohols, and semiacetals are attained more rapidly than those involving semiacetals, alcohols, acetals, and water. Semiacetals, in fact, usually yield aldehydes so rapidly that they form aldehyde derivatives under the same conditions as are necessary for the corresponding aldehydes. Acetals, however, need to be heated in the presence of dilute acid to effect their hydrolysis to aldehydes.

Whether or not a sugar will respond to an aldehyde test depends upon the equilibria concerned. The Schiff reagent test involves an addition to the carbonyl which is reversible. Since the sugars do not give the test, we may conclude either that the semiacetal more effectively removes the free aldehyde form of the sugar from solution than does a reaction with the magenta reagent, or that free sulphurous acid reacts more rapidly and completely with the sugar than does the magenta reagent.

In the reactions of hydroxylamine and hydrazines with carbohydrates the equilibria involved favor oxime and hydrazone formation. The semiacetal sugars do not appear under Tests 4a and 4b, because their oximes are soluble in water and insoluble in ether, and hence they are not isolated under the conditions of the test. They will, however, appear under Test 4c. Hydrazones are also soluble, as a rule, but the osazones are sparingly soluble and easily prepared.



$$\begin{array}{l}CHO\\ |\\ CHOH\\ |\\ CHOH\\ \vdots\end{array} \xrightarrow[-H_2O]{C_6H_5-NH-NH_2} \begin{array}{l}CH=N-NH-C_6H_5\\ |\\ CHOH\\ |\\ CHOH\\ \vdots\end{array}$$

Phenylhydrazone

$$\xrightarrow[-H_2O]{2\,C_6H_5NH-NH_2} \begin{array}{l}CH=N-NH-C_6H_5\\ |\\ CH=N-NH-C_6H_5\\ |\\ CHOH\\ \vdots\end{array} + C_6H_5NH_2 + NH_3.$$

Phenylosazone

Tollen's reagent and Fehling's solution react with sugars slowly in the cold. The former cannot be used when warm, since it then oxidizes alcohols. The latter does not react with sugars at room temperature but reacts at 100° much more rapidly with aldehydes and sugars than with alcohols.*

If a disaccharide or a polysaccharide is in the form of a complete acetal, the reactions with phenylhydrazine and Fehling's solution fail. These reactions take place with semiacetals, but acetals must be hydrolyzed first to liberate the aldehyde nucleus, so that disaccharides, polysaccharides, and glucosides may fail to give the tests in the time allowed. Hydrogen ion, but not hydroxide ion, catalyzes the hydrolysis. Thus, glucose and fructose as monosaccharides yield osazones directly. The disaccharides lactose and maltose give osazones without hydrolysis, but cane sugar (sucrose) must be hydrolyzed first. Hence the structure of sucrose must involve in the linkage between the glucose and fructose molecules the semiacetals of each hexose, but the linkage between the two glucose molecules in mannose leaves undisturbed one of the semiacetal structures.

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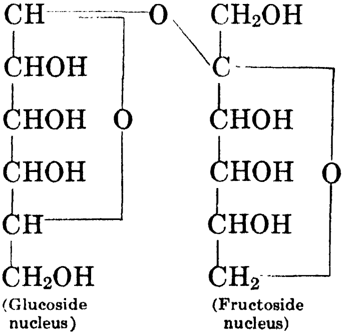
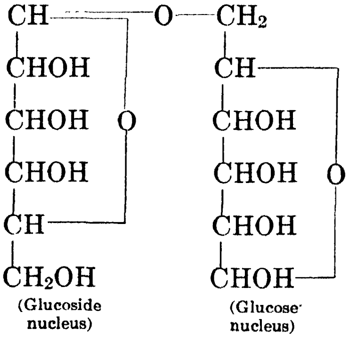
* The cupric copper is held in solution in the presence of strong alkali in the form of a complex tartrate ion, presumably $C_4H_2O_6Cu^{--}$. Cuprous copper does not form such a complex, and hence, as the reaction proceeds, it appears as the insoluble oxide or hydroxide. The reaction does not involve exactly two mols of cupric ion for each sugar molecule. Side reactions occur, involving slower oxidations of other parts of the molecule. The ketoses also reduce Fehling's solution.



Sucrose



Maltose

The osazones are easily prepared and may serve as a means of identifying the particular sugar. The osazones of most sugars are yellow. Mannosazone is colorless. Some simple aldehydes and ketones, if overlooked in Test 4, will be precipitated as hydrazones in Test 5c. Hydrazones are usually colorless substances.

Test 5a. Treat 0.1 g. of the substance with 5 cc. of water and two drops of a strong solution of alpha-naphthol in alcohol; then add 5 cc. of concentrated sulphuric acid as a lower layer. A red ring between the layers and a deep violet color in the solution after the layers are mixed indicate the presence of a carbohydrate.

This test is also given by polyhydroxy acids and by some unsaturated aldehydes. The substance should be free from filter paper, the reagents should be pure, and the sulphuric acid and alpha-naphthol, when mixed, should produce a yellow solution.

Test 5b. If Test 5a is positive, dissolve 0.1 g. of the unknown in a little water, add 5 cc. of Fehling's solution, and heat the mixture by immersion in a boiling-water bath for two minutes. If no change occurs, repeat the experiment after first boiling the sample for five minutes in 1 cc. of water to which one drop of concentrated hydrochloric acid has been added. The acid solution should be neutralized before the Fehling's solution is added. Reduction of the Fehling's solution before acid hydrolysis indicates a sugar with an aldehyde or a ketone or a semiacetal group. If hydrolysis is necessary before reduction occurs, it is a complete acetal or glucoside.

Test 5c. Heat a solution of 0.25 g. of the carbohydrate, 0.5 g. of phenylhydrazine hydrochloride, 1 g. of sodium acetate, and 5 cc. of water for twenty minutes in a water bath at from 90° to 100°. If the salt of phenylhydrazine is not available, use 0.5 cc. of the free base and 0.5 cc. of glacial acetic acid in place of the phenylhydrazine hydrochloride and sodium acetate. The osazone usually separates as a precipitate. If it does not do so while on the water bath, set the mixture aside to cool. Some disaccharides, polysaccharides, and glucosides give osazones only after hydrolysis by boiling with dilute acid (compare Test 5b). The osazone may be purified by recrystallization from ethyl alcohol, washing with pure methyl alcohol, and drying. It may be identified by its melting point or crystal form.

Pentoses may be recognized by the deep red color produced on warming with phloroglucinol and concentrated hydrochloric acid. Starches and celluloses show an organized structure when examined under the microscope. Starches give a blue coloration and dextrines a reddish coloration with a dilute solution of iodine in potassium iodide.

TEST 6. HYDROXY COMPOUNDS, ALCOHOLS, ENOLS, AND PHENOLS

Carbon compounds containing oxygen are more soluble in water than are the corresponding hydrocarbons. Of the remaining classes of compounds in this division, namely, alcohols, ethers, and hydrocarbons, the alcohols are higher boiling and more soluble in water than are the corresponding members of the other two types of compounds. Consequently, if the compound under examination has not given positive results in any of the previous tests, a study of its boiling point and of its solubility in water often permits its designation as an alcohol. This is true especially in the case of the lower alcohols, glycols, and polyhydric alcohols, and is the basis of Test 6a. The certification of negative results in Tests 1 to 5 is necessary, since the compounds considered there, with the exception of esters and acid anhydrides, are similar to alcohols in their physical properties. An increase in the ratio of carbon to oxygen decreases solubility in water, so that the higher alcohols approach the insolubility of hydrocarbons and do not appear in Test 6a.

The basis of Test 6b and of Test 6c is the formation of an ester of the alcohol. Esterification may be carried out in a variety of ways. Alternative methods are suggested, since not all alcohols will respond to any one esterification procedure. Tertiary alcohols readily form ethylenes under the conditions of ordinary esterification. Other hydroxylated compounds, such as β-hydroxy aldehydes, β-hydroxy ketones, and β-hydroxy acids, also lose water readily, forming the corresponding unsaturated derivatives.

The detection of the esterification reaction does not necessitate isolation and purification of the ester. The major reactions may be expressed by the equations

$$\text{I. } ROH + C_6H_5COCl \xrightarrow[\text{pyridine}]{\text{NaOH or}} C_6H_5COOR + \begin{array}{l}\text{NaCl or pyridin-}\\ \text{ium chloride.}\end{array}$$

$$\text{II. } ROH + (CH_3CO)_2O \longrightarrow CH_3COOR + CH_3COOH.$$

At the conclusion of reaction I the mixture contains pyridine (or aqueous NaOH), ester, and salts, including chlorides and benzoates from hydrolysis of excess benzoyl chloride. After acidifying the mixture to form the water-soluble pyridinium salt the ester and benzoic acid are extracted with ether. The acid is then removed as a water-soluble salt by washing the ether layer with dilute alkali. If the original contained a carboxyl group, the carbonate washing would have to be eliminated, since the substance desired would be removed as a salt. The final ether solution would then contain any ester, any unchanged alcohol (unless very soluble in water), and possibly benzoic acid. The small quantities used preclude further purification. Care must be taken to insure the complete hydrolysis of excess benzoyl chloride. Any acid impurity may be directly titrated; an ester will neutralize alkali only after heating with the base. The presence of an ester will therefore be evident if, after the titration of any free acid, more alkali is neutralized upon heating the sample with an excess of the reagent. If the original is acidic (a hydroxy acid), the test may still be used; but if the original is itself an ester, Test 6b cannot be used unless the new ester formed is isolated, purified, and its equivalent weight on hydrolysis compared with that of the original. Enols and phenols may esterify under the conditions of this test. Acids may form acid anhydrides, but these usually titrate as acids.

At the conclusion of reaction II, above, the mixture contains an ester, the excess acid anhydride, and the free acid. The last two react rapidly with alkali; the ester, more slowly. Ester formation, therefore, can be detected by a rapid titration of the reaction mixture and a comparison of the amount of alkali used with the amount that would be necessary if no acetic anhydride had disappeared in the reaction.

Benzoyl chloride will esterify alcohols in the presence of alkali even if water is present, since alcoholysis of the acid chloride is more rapid than hydrolysis. The reaction is known as the Schotten-Baumann reaction.

Test 6a. If all the preceding tests have given negative results, determine the solubility of the unknown in water by shaking 5 g. with gradually increasing, measured quantities of water. A solid or liquid boiling above 100° and soluble at room temperature to the extent of one or more parts in fifty of water is an alcohol. One which is very soluble in water (1 to 5) may be regarded as an alcohol even if it boils below 100°. A substance boiling below 100° and not soluble in fifty parts of water is not an alcohol. A few cyclic and unsaturated ethers are sufficiently soluble to respond to Test 6a.

Test 6b. Dissolve 2 g. of the substance in 5 g. of dry pyridine,* add 1 g. of benzoyl chloride, and allow it to stand overnight.

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* Instead of the pyridine, 20–30 cc. of 10 per cent NaOH may be used. In this case, constant shaking is necessary, as the benzoyl chloride, the ester, and possibly the unknown are insoluble in water. When the odor of benzoyl chloride has disappeared, proceed as directed on page 182.

Add an equal volume of water slowly, cooling if necessary, and shake the mixture until there is no detectable odor of benzoyl chloride. Pour the mixture into cold dilute sulphuric acid, extract it with ether, wash the ether with cold dilute sodium carbonate, and distill off the ether. Examine a portion of the residue for the presence of an ester as follows:

First titrate it with 1.0 *N* sodium hydroxide, using phenolphthalein as the indicator, and after the end point is reached, add 5 cc. of the 1.0 *N* alkali and an equal volume of alcohol. Boil the mixture gently under a reflux condenser for half an hour, then cool it and back-titrate the excess alkali with 1.0 *N* acid, using phenolphthalein as indicator. Estimate the probable error introduced by the heating of the alkali in glassware, or perform a suitable blank to determine the error. Alkali used up on heating represents equivalent quantities of ester present in the sample, and hence the presence of an alcohol group in the original substance.

If the original substance is an acid, the washing with dilute sodium carbonate has to be omitted and the possible formation of the mixed acid anhydride should be considered. Any ester formed will be contaminated with benzoic acid in the ether extract unless the ether extract has been thoroughly washed with the dilute alkali.

Test 6c. By means of a pipette, measure out two 2-cubic-centimeter samples of freshly distilled acetic anhydride, one into a flask or beaker containing 50 cc. of 1.0 *N* sodium hydroxide, the other into a bomb tube which contains about 0.5 g. of the unknown. Seal the bomb, taking care to volatilize none of the substances. Heat it on the water bath for an hour. Titrate the alkaline solution of the first sample with 1.0 *N* acid, using phenolphthalein as an indicator, to determine the alkali equivalent of the acetic anhydride used. After heating the bomb, cool it and pour the contents over a little finely cracked ice in a flask. Wash out the bomb with cold water, adding the washings to the flask. Take the usual precautions of quantitative work in order to effect the transfer. Place a small piece of litmus paper in the solution and add 1.0 *N* alkali rapidly until an alkaline reaction is observed. Add phenolphthalein and titrate the excess alkali quickly with 1.0 *N* acid.

Calculate the alkali equivalent of the contents of the bomb. If it is less than that of the blank, the substance is an alcohol, and the difference in the alkali equivalents of the blank and of the contents of the bomb is equal to the number of alcohol equivalents which have reacted with the acetic anhydride. From the results calculate the equivalent weight of the alcohol, which should be less than 500. The numerical result should not be considered quantitatively correct until it has been checked with a second sample which has been heated with the acid anhydride for a longer time. Greater accuracy may be obtained by using larger quantities of acetic anhydride and sample. If the unknown substance is an acid, its neutralizing power must be taken into consideration in the above calculations. This method is applicable to hydroxy esters.

Hydroxy derivatives, including alcohols, ionize, forming hydrogen ions. The concentration of hydrogen ion in pure ethyl alcohol is about 10^{-9} mols per liter, whereas its concentration in pure water is 10^{-7} mols per liter. Alcohol, therefore, is a much weaker acid than is water. Alcohols form metallic salts (alcoholates). These derivatives are completely destroyed by the stronger acid, water; that is, in water they are hydrolyzed to alcohol almost completely, and so cannot be prepared in aqueous solution. The sodium alcoholates are formed by the action of metallic sodium on the anhydrous alcohol:

$$ROH + Na \longrightarrow RONa + \tfrac{1}{2}\ H_2.$$

The evolution of hydrogen is taken as evidence of the reaction, but this may be due to a trace of water or of the enol form of a ketone. Moreover, many alcohols react sluggishly. As a test for alcohols, therefore, the reaction is not satisfactory.

The alcohols do not ionize perceptibly to give hydroxide ion. They do, however, react with halogen acids to form alkyl halides.

$$ROH + HCl \rightleftarrows RCl + H_2O.$$

This reaction is reversible, and is very slow. It is therefore not suitable as the basis of a test for the hydroxyl group.

Phosphorus trichloride and phosphorus pentachloride react with alcohols to form the corresponding halides.

$$3\ ROH + PCl_3 \longrightarrow 3\ RCl + P(OH)_3.$$
$$ROH + PCl_5 \longrightarrow RCl + POCl_3 + HCl.$$

The alkyl chloride must be isolated and identified as evidence of the substitution of the hydroxyl group by chlorine. This limits the usefulness of the reactions as the basis of a test for alcohols. Moreover, other reactions take place simultaneously, sometimes almost to the exclusion of those represented above. These are of the types

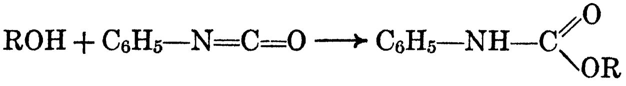
$$\text{I.}\quad 3\,ROH + PCl_3 \longrightarrow P(OR)_3 + 3\,HCl.$$
$$\text{II.}\quad 3\,C_nH_{2n+1}OH + PCl_3 \longrightarrow 3\,C_nH_{2n} + P(OH)_3 + 3\,HCl.$$

Esters of phosphorous and phosphoric acids are thus formed through the use of the phosphorus chlorides. Secondary and tertiary alcohols are particularly likely to form olefines upon treatment with acid chlorides. Since reaction I, above, does not involve rupture of the carbon-oxygen bond of the alcohol, whereas alkyl halide formation does, it has been suggested that reaction I takes place rapidly in all cases, followed by reactions of the ester as follows:

$$P(OR)_3 + 3\,HCl \longrightarrow P(OH)_3 + 3\,RCl.$$
$$P(OC_nH_{2n+1})_3 \longrightarrow P(OH)_3 + 3\,C_nH_{2n}.$$

Carboxylic acid chlorides with primary and secondary alcohols usually undergo the reaction of ester formation, but with tertiary alcohols often yield the alkyl halides or olefines.

The esters of *m*-nitrobenzoic acid, *p*-nitrobenzoic acid, the dinitrobenzoic acids, and chlorobenzoic acid are usually solids and are convenient derivatives for the identification of alcohols. Phthalic anhydride reacts with primary and secondary, but not with tertiary, alcohols, and more rapidly with the primary than with the secondary types. These differences form one of the tests for the different classes of alcohols (compare Houben-Weyl, Methoden der organischen Chemie, Part II, p. 756 (1911)). Phenylisocyanate and phenylthioisocyanate react with alcohols to form phenyl carbamic esters and phenyl thiocarbamic esters,



$$ROH + C_6H_5\text{—}N\text{=}C\text{=}O \longrightarrow C_6H_5\text{—}NH\text{—}C\begin{matrix}\nearrow O\\ \searrow OR\end{matrix}$$

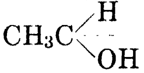
The products are crystalline and are good derivatives for identification. Ammonia, amines, enols, phenols, and water also react readily with isocyanates.

The Grignard reagent reacts with alcohols,

$$CH_3MgCl + ROH \longrightarrow CH_4 + ROMgCl.$$

The methane may be measured volumetrically and the reaction used for the quantitative estimation of alcohols in the absence of ammonia, amines, acids, phenols, water, etc., — that is, in the absence of other substances giving any appreciable concentration of hydrogen ion.

The oxidation products of alcohols can be used as a clue to the nature of the alcohol only when they are themselves subjected to a rigid examination and definitely identified. Oxidation cannot readily be used to demonstrate the presence of a hydroxyl group, since alcohols, as a class, do not differ sufficiently from other oxygenated compounds in their ease of oxidation.

Similarly, the "iodoform test" for ethyl alcohol is really a test for the acetyl group, $CH_3\underset{|}{C}{=}O$. Any compound containing this group, or in which the group may be formed by oxidation from  $CH_3C\begin{smallmatrix}H\\OH\end{smallmatrix}$, will yield iodoform when treated with iodine and alkali.

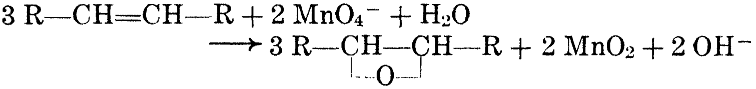
TEST 7. UNSATURATED HYDROCARBONS

Tests 7a and 7b depend on the rapid decolorization of elementary bromine and of permanganate ion by unsaturated compounds. Phenols and enols may also react rapidly with these reagents. With bromine the latter react to produce hydrogen bromide (see Test 2c), whereas the ethylenes and acetylenes form addition products.

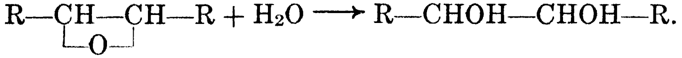
$$R{-}CH{=}CH{-}R + Br_2 \longrightarrow R{-}CHBr{-}CHBr{-}R$$

Hydrogen bromide is sparingly soluble in dry carbon tetrachloride, and the vapor on coming in contact with moist air forms a fog, or with ammonia vapor forms a cloud of ammonium bromide. The evolution of hydrogen bromide serves to distinguish between the rapid decolorization of bromine due to addition and that due to substitution. Unsaturated acids, such as cinnamic acid, add bromine slowly but react readily with alkaline permanganate (Test 7b). The presence of negative groups (CO_2H, Br, C_6H_5) adjacent to a double bond inhibits the addition of bromine. Addition reactions as well as substitution reactions are catalyzed by sunlight, surfaces, and solvents.

The product of the reaction between an unsaturated substance and permanganate ion in alkaline solution is usually an ethylene oxide or a glycol, and manganese dioxide,

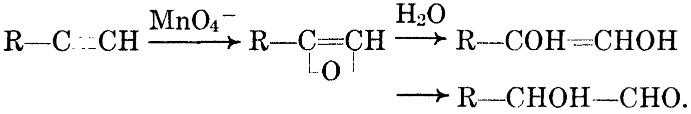


$$\mathrm{3\,R{-}CH{=}CH{-}R + 2\,MnO_4^- + H_2O \longrightarrow 3\,R{-}\underbrace{CH{-}CH}_{O}{-}R + 2\,MnO_2 + 2\,OH^-}$$



$$\mathrm{R{-}\underbrace{CH{-}CH}_{O}{-}R + H_2O \longrightarrow R{-}CHOH{-}CHOH{-}R.}$$

In most cases the oxide is too readily hydrolyzed to be isolated. An acetylene derivative may give an aldehyde:



$$\mathrm{R{-}C{\equiv}CH \xrightarrow{MnO_4^-} R{-}\underbrace{C{=}CH}_{O} \xrightarrow{H_2O} R{-}COH{=}CHOH \longrightarrow R{-}CHOH{-}CHO.}$$

Since aldehydes and alcohols are themselves oxidized by alkaline permanganate, the reaction may not stop with the products outlined above. With care a 50 per cent yield of glycol may be obtained. If the alkali is too concentrated or too much time is allowed, permanganate may be reduced by almost any organic compound.

The $\mathrm{{-}C{\equiv}CH}$ group is weakly acidic and forms solid cuprous and silver salts which are sparingly soluble. The precipitate formed by passing acetylene into ammoniacal solutions of the metals usually has the composition C_2Ag_2 or C_2Cu_2, but may contain water or an acid salt such as C_2HAg.

Test 7a. Add, drop by drop, a dilute solution of bromine in carbon tetrachloride to a mixture or solution of the unknown in dry carbon tetrachloride. Shake the mixture and allow it to stand after each addition. If the bromine is decolorized, blow across the mouth of the tube after several drops have been used, to test for the evolution of hydrogen bromide, which is shown by the formation of a cloud. Should the bromine be decolorized without the formation of hydrogen bromide, it shows the presence of a double or triple bond. Rapid decolorization of the bromine, with evolution of hydrogen bromide, is almost certain in the presence of all phenols and enols and many aldehydes and ketones.

Often the addition of bromine water to a few drops of the unknown is sufficient to give the test, but the evolution of hydrogen bromide could then be detected only by titration. In case of doubt as to the presence of a substitution or addition reaction, carry out the reaction between the bromine in carbon tetrachloride and excess of the unknown in such a way that no hydrogen bromide escapes. Add water to the reaction mixture, and titrate the acid present, performing a blank test with amylene and the same amount of bromine solution, to detect acid introduced from any other source.

Test 7b. Shake a little of the unknown with a few cubic centimeters of a dilute, slightly alkaline solution of potassium permanganate. Disappearance of the purple color of the permanganate, with the production of the green manganate ion or a precipitate of brown manganese dioxide, shows the presence of an unsaturated compound. This conclusion is not valid if oxygen-containing compounds other than acids, esters, and ethers are present.

Test 7c. If the substance is a liquid or a gas, and if it is neither an acid nor a phenol, shake it with an ammoniacal solution of cuprous chloride. The formation of a solid precipitate indicates a triple bond, to which one hydrogen is attached.

The failure of Tests 1–7, inclusive, indicates an ether, a hydrocarbon, or a difficultly saponifiable ester.

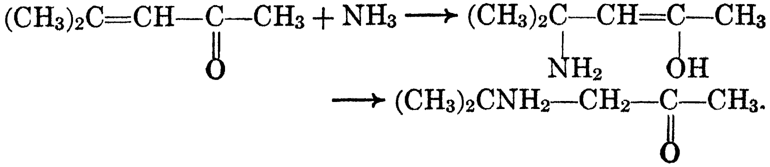
Many other reagents give addition reactions with unsaturated compounds. Concentrated sulphuric acid forms acid sulphuric esters,

$$CH_2{=}CHR + H_2SO_4 \longrightarrow CH_3{-}CHROSO_3H,$$

which in turn may hydrolyze to alcohols. The reaction is slow unless SO_3 is present (fuming acid). Acids thus catalyze the addition of water to form alcohols. Acetylene gives acetaldehyde when heated with acidified water:

$$HC{\equiv}CH + H_2O \longrightarrow H_2C{=}CHOH \longrightarrow H_3C{-}CHO.$$

Ammonia, amines, and the Grignard reagent do not add unless the ethylene bond is conjugated with a carbonyl or imide group, allowing 1–4 addition:



$$(CH_3)_2C{=}CH{-}\underset{\overset{\|}{O}}{C}{-}CH_3 + NH_3 \longrightarrow (CH_3)_2\underset{\overset{|}{NH_2}}{C}{-}CH{=}\underset{\overset{|}{OH}}{C}{-}CH_3$$

$$\longrightarrow (CH_3)_2CNH_2{-}CH_2{-}\underset{\overset{\|}{O}}{C}{-}CH_3.$$

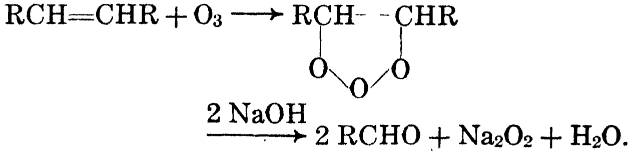
Iodine does not add rapidly, but the reaction is apparently catalyzed by mercury salts and by bromine or chlorine. Hypochlorous and hypobromous acids add more rapidly than do the corresponding halogens. Hence, when ethylene is treated with chlorine water, an almost theoretical yield of glycol chlorhydrin ($CH_2Cl—CH_2OH$) is obtained. This is true even though in the equilibrium $Cl_2 + H_2O \rightleftarrows HCl + HOCl$ the concentration of hypochlorous acid is very small. Other reactions that are possible under the same conditions, namely, addition of chlorine, substitution by chlorine, and oxidation, are relatively slow.

Of the halogen acids, concentrated hydriodic acid reacts the most readily to form additive compounds. Concentrated hydrochloric acid reacts very slowly if at all.

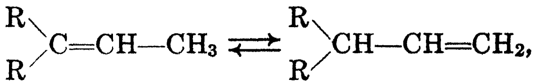
The oxides of nitrogen NO_2 and N_2O_3 add to ethylenes to form combinations of nitro and nitrite derivatives. Some inorganic acid halides, such as NOCl, $AsCl_3$, $SbCl_3$, PCl_3, and SCl_2, add to acetylenes and ethylenes. The reaction is used to prepare mustard gas:

$$2\ H_2C{=}CH_2 + SCl_2 \longrightarrow (ClCH_2—CH_2)_2S.$$

Ozone reacts to give ozonides which react with alkali to form metallic peroxides and aldehydes or ketones:



The molecule is split at the position of the double bond, and for this purpose ozone is more reliable than other oxidizing agents ($KMnO_4$, H_2CrO_4, NaOH fusion in O_2, etc.), because the others have been observed at times to rupture the molecule near rather than at the double bond. The anomaly may be due to an actual shift of the double bond,



catalyzed under the conditions of the oxidation.

Diazomethane (CH_2N_2) adds to ethylenes, forming pyrazolines. Unsaturated hydrocarbons apparently add to themselves, at very high temperatures, to give polymerized products (acetylene to benzene). Some ethylenes, like aromatic hydrocarbons, undergo the Friedel-Crafts reaction.

Of the above reactions those with fuming sulphuric acid and with the halogens are used for quantitative analysis. Aromatic hydrocarbons are readily soluble in fuming sulphuric acid if the SO_3 content is high. The olefine and aromatic hydrocarbon content of gases and liquid hydrocarbon oils may be determined by observing the decrease in volume of the sample when agitated with 15 per cent fuming sulphuric acid. Saturated paraffin hydrocarbons are unaffected in the cold. The unsaturation of fats is usually expressed as the grams of halogen calculated as iodine absorbed by 100 g. of fat. This "iodine number" is obtained by treating the sample with a known excess of a mixture of iodine and mercuric chloride in alcohol, or a mixture of iodine and chlorine in acetic acid, and titrating the excess reagent with thiosulphate in the presence of potassium iodide.

TEST 8. AROMATIC HYDROCARBONS

The basis of Test 8a is the Friedel and Crafts reaction:

$$C_6H_6 + RCl \xrightarrow{AlCl_3} C_6H_5R + HCl.$$

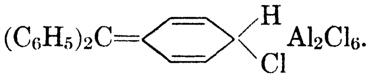
Aluminum chloride promotes the reaction, but it must be used in considerable quantity, since it disappears in the formation of complex compounds with the products of the reaction. The particular alkyl halide used in the test is chloroform, and the product of the simplest reaction possible, wherein all the halogen atoms are replaced by aromatic nuclei, is known as a triarylmethane:

$$3\,C_6H_6 + CHCl_3 \xrightarrow{AlCl_3} (C_6H_5)_3CH + 3\,HCl.$$

In addition to this simple reaction more complex changes occur, in which triarylchloromethanes and corresponding quantities of diarylmethanes and monoarylmethanes are formed:

$$5\,C_6H_6 + 2\,CHCl_3 \longrightarrow (C_6H_5)_3CCl + (C_6H_5)_2CH_2 + 5\,HCl.$$

The triarylchloromethanes with concentrated acids or with certain salts, including aluminum chloride, form the halochromic salts, which are colored and are readily ionized. These are thought to have quinoid structures of the type

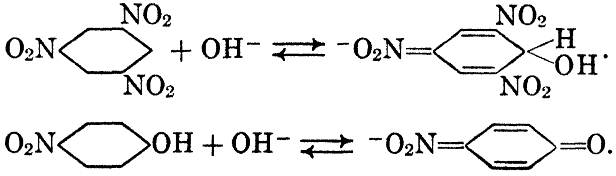


The result of the test, then, is a distinct coloration, not to be confused with the yellow and brown resins of aliphatic derivatives. Since mere traces of aluminum chloride do not suffice, and since it is difficult to keep the salt uncontaminated by moisture, the aluminum chloride is freshly resublimed to make certain that the material at hand is not simply a partially hydrated sample. Many derivatives of the aromatic hydrocarbons give the characteristic coloration, so that the test may often be used to detect the aromatic nucleus even in the presence of more characteristic groups. The substances actually formed under the conditions of the test are probably more complex than the simple type suggested above.

Test 8b depends upon the formation of colored nitro derivatives of the aromatic hydrocarbons,

$$C_{10}H_8 + HNO_3 \longrightarrow C_{10}H_7NO_2 + H_2O.$$

Although some of the simple aromatic nitro compounds are colorless when pure, most of them are at least yellow or orange, and, as ordinarily prepared, the yellow or orange color is nearly always present. The simple aromatic nitro compounds do not form colored salts with alkalies, but the crude substances always contain enough of the polynitro derivatives, such as trinitrobenzene, or traces of oxidation products, such as nitrophenols, to give different colors in acid and in alkali. These changes may be represented as follows:


NO_2
O_2N
NO_2
$+ OH^- \rightleftarrows {}^-O_2N=$
NO_2
H
OH
NO_2
O_2N
$OH + OH^- \rightleftarrows {}^-O_2N=$
=O.

The aromatic hydrocarbons usually nitrate with ease, for example, at low temperatures and without excessive quantities of sulphuric and nitric acids. Many derivatives, however, require more severe treatment. The insolubility in water of nearly all aromatic nitro derivatives makes their separation very simple. In case of doubt that a water-insoluble product is a nitro derivative, rather than a simple oxidation product, the substance should be subjected to the test for nitro derivatives (Division II, Test 3a).

Aliphatic derivatives, particularly aldehydes, ketones, ethylenes, and alcohols, should not be subjected to Test 8b. Severe explosions have been known to occur on account of the formation of aliphatic nitro derivatives and nitrate esters.

Many other reactions of aromatic compounds are in reality due to combinations of aromatic nuclei with other groups. These are sometimes so characteristic, as in the case of phenols and primary aromatic amines, that they have warranted separate classification. Two other common reactions of the aromatic hydrocarbons, as well as of their derivatives, are halogenation in the presence of iron filings and sulphonation with fuming sulphuric acid. In these cases, in order to detect the reaction as one involving an aromatic group, the product must be isolated and identified as an aromatic halide or an aromatic sulphonic acid.

Test 8a. Sublime some dry aluminum chloride in a small tube so as to form a heavy film of aluminum chloride on the surface of the glass. Cool it and add to it a drop or crystal of the unknown dissolved in five drops of chloroform. Stopper the tube and let the liquid come in contact with the film of aluminum chloride. The formation of a bright color, from orange to blue, indicates an aromatic nucleus.

Test 8b. Do not perform this test unless all previous tests have given negative results. Treat the unknown (**Caution!**) with a mixture of equal quantities of concentrated sulphuric and nitric acids at room temperature. If no reaction ensues, warm the mixture from thirty to sixty minutes on a water bath at 60°, or higher if necessary to get evidence of a reaction. Cool the mixture and pour it carefully into ten times its volume of cold water. Examine the product. A new compound, insoluble in cold water, generally yellow in color, often turning red in alkali, indicates the formation of an aromatic nitro body. If the original substance did not contain nitrogen, or if it failed to give a positive test for a nitro group, test the new compound for a nitro group (Division II, Test 3a). A positive test indicates the presence of an aromatic nucleus.

TEST 9. ETHERS; UNSAPONIFIABLE ESTERS

The oxygen and sulphur atoms display to some extent the property shown by the nitrogen atom in forming "onium" salts (see page 193). The reaction involved is the addition of some positive ion, usually hydrogen ion or the ion of some alkyl radical, to the atom in question. Ions of the type R_4N^+ and R_3S^+ are common, but the corresponding ion, R_3O^+, is not definitely known. The ammonium ion, NH_4^+, is readily formed from ammonia and aqueous acid, but the basic properties of sulphur in sulphides and of oxygen in ethers are too weak to permit appreciable salt formation in the presence of water. Concentrated, or 95 per cent, sulphuric acid, however, readily dissolves ethers, and upon dilution with water the unchanged ether is precipitated. Ethers may be hydrolyzed to alcohols by acidulated hot water. To avoid this the process of solution and reprecipitation is completed in the cold. The solution of ether is presumably due to oxonium salt formation with the acid:

$$2\,R_2O + H_2SO_4 \rightleftarrows 2\,(R_2OH)^+ + SO_4^{--}.$$

The addition of water displaces the equilibrium to the left, perhaps owing to the reaction

$$2\,H_2O + H_2SO_4 \rightleftarrows 2\,(H_3O)^+ + SO_4^{--}.$$

Concentrated sulphuric acid dissolves ethylenes, though slowly. The aromatic hydrocarbons react with sulphuric acid in the cold if fuming acid is employed. However, the reaction products, namely, aliphatic acid sulphates and aromatic sulphonic acids respectively, are soluble in dilute sulphuric acid. The observations in the case of ethers are rapid solution with the evolution of heat, and the separation again of the original substance on the addition of water. Oxygen present in any form may cause the substance to be soluble in concentrated sulphuric acid, but the hydrocarbons are not soluble except as noted above.

Test 9. If the unknown is a liquid, test its solubility in cold concentrated sulphuric acid. Use 1 cc. of the unknown to 2 cc. of acid. If it is soluble, recover the substance by diluting the acid with cracked ice and taking off the top layer. Wash it with dilute sodium carbonate solution and determine its boiling point. If the substance dissolves in sulphuric acid and is recovered unchanged, it is an ether or an unsaponifiable ester. This test is, of course, valueless if any of the tests 1 to 8 have been positive.

DIVISION II. COMPOUNDS CONTAINING NITROGEN

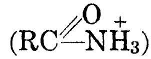
TEST 1. SALTS OF AMMONIA, AMINES, HYDRAZINES, HYDROXYLAMINES, AMIDINES, OXIMES, AND AMIDES

The salts of ammonia and of the amines have the general formula $R_4N^+X^-$. They are highly ionized in aqueous solution. If any of the four groups attached to the nitrogen atom is a hydrogen atom, there is a rapidly established equilibrium, in aqueous solution, between the ammonium or substituted ammonium ion, on the one hand, and the ammonia, or amine and hydrogen ion, on the other, according to the equation

$$R_3NH^+ \rightleftarrows R_3N + H^+.$$

The equilibrium constant of this reaction varies with the nature of the substituted groups; thus, for ammonium ion

$$K = \frac{(NH_3) \times (H^+)}{(NH_4{}^+)} = 5.2 \times 10^{-10}.$$

Corresponding constants for methyl ammonium ion, $CH_3NH_3{}^+$, and anilonium ion, $C_6H_5NH_3{}^+$, are 2×10^{-11} and 2×10^{-5} respectively.* If an acyl group is substituted for hydrogen in ammonium ion, the corresponding equilibrium constant is very much greater, and in solution in water the ion  $(RC(=O)\overset{+}{N}H_3)$ is almost completely dissociated into hydrogen ion and the amide.

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* The value of these equilibrium constants can be obtained from K_b, the dissociation constant of the amines as bases, by the equation $K = K_w/K_b$, where K_w, the dissociation constant of water, is 10^{-14}. K_b for ammonia or ammonium hydroxide is 1.9×10^{-5}; hence in the dissociation of ammonium ion to give hydrogen ion $K = \frac{1 \times 10^{-14}}{1.9 \times 10^{-5}} = 5.2 \times 10^{-10}$. In neither K nor K_b is a distinction made between NH_3, NH_4OH, or any other compound between ammonia and water.

If sodium hydroxide is added to an aqueous solution of an ammonium or an amine salt, the hydroxide ion will combine with the hydrogen ion formed by the reversible reaction

$$R_3NH^+ \rightleftarrows R_3N + H^+,$$

and the equilibrium will be displaced so as to set free the ammonia or amine. The reaction may be represented by the equation

$$R_3NH^+ + OH^- \longrightarrow H_2O + R_3N.$$

This is the fundamental reaction of Tests 1a and 1b.

In Test 1a this reaction is detected by the odor of the ammonia or amine liberated, and is applicable to salts of the lower aliphatic amines as well as to ammonium salts. In Test 1b the fundamental reaction is detected by separating the amine from the ions by extraction with ether, a solvent in which the higher amines are more soluble than in water. The presence of the amine in the ethereal layer can be shown by precipitating the sulphate of the amine with a trace of concentrated sulphuric acid, since these salts are sparingly soluble in ether.

The general formula of the amino acids is of a type similar to that of the ammonium salts, since the carboxyl or other markedly acid group must combine with the amino group in the same way as an acid combines with an amine.* Nevertheless amino acids fail to respond to these tests; for, on reaction with hydroxide ion, they form compounds of the type $NH_2—CHR—COO^-$, which, being ionic, will not be extracted from aqueous solution by ether.

Amides and some other substances (see Test 7) form ammonia or amines on treatment with sodium hydroxide, but in general these reactions are too slow at ordinary temperatures to be confused with the reaction of a salt with sodium hydroxide. There are occasional exceptions (formamide, for example) in which an amide or other nitrogen compound will hydrolyze so rapidly that it may be mistaken for an ammonium or an amine salt.*

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* Aminoacetic acid should be represented by the structure $^+NH_3—CH_2—COO^-$ if ammonium acetate is written $CH_3CO\overset{-}{O}\overset{+}{N}H_4$.

The quaternary ammonium salts, in which none of the four groups attached to the nitrogen is the hydrogen atom, do not give hydrogen ion in solution. Consequently they do not give amines when treated with sodium hydroxide at ordinary temperatures, and so they fail to respond to Tests 1a and 1b. They are distinguished from the other organic compounds by the fact that although they are not metallic salts they give in water neutral or slightly basic solutions, which are good conductors of electricity.

A salt may behave as an acid or as a base toward titration, according to the strength of the acid and base from which it is formed, and upon the hydrogen ion concentration at which the indicator used changes color. If the compound is to be subjected to Test 2, this fact must be taken into account.

The salts of hydrazines, hydroxylamines, oximes, and amides with acids are similar in behavior to those of the amines, except that in general they correspond to salts of weaker bases. Only solid substances need be subjected to the following tests.

Test 1a. Treat about 0.1 g. of the finely divided substance with a few drops of 6 *N* sodium hydroxide on a watch glass, and note any odor which is produced. An ammoniacal odor indicates that the substance is an ammonium or an amine salt.

Test 1b. Treat two samples of the unknown as follows: (1) Shake about 0.1 g. of the substance with 10 cc. of dry ether. Decant off the ether and stir it with a glass rod moistened with concentrated sulphuric acid. (2) Shake about 0.1 g. of the substance with 5 cc. of water, 2 drops of pure 6 *N* sodium hydroxide, and 10 cc. of ether. Pipette off the ether layer, dry it with solid potassium hydroxide, decant off the ether, and stir it with a glass rod moistened with concentrated sulphuric acid. If there is a markedly greater precipitate in (2) than in (1), it shows that an ether-soluble base is liberated by the action of aqueous sodium hydroxide on the substance, and therefore that the substance is a salt. A slight precipitate or turbidity in (1) is due to the presence of moisture or a trace of free base in the sample. If a heavy precipitate is formed in both (1) and (2), the substance is not a salt but a free base.

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* Amides that hydrolyze readily melt at low temperatures (usually below 100°) and are soluble in water.

The aqueous phase in (2) may be withdrawn and after neutralization may be tested for any negative ions that are suspected — for example, chloride or sulphate ions if the substance contains chlorine or sulphur.

The free base can be obtained from a salt by treatment with aqueous sodium hydroxide and distillation if Test 1a is positive, or by extraction with ether if Test 1a is negative but 1b is positive. The base obtained by distillation may be collected in a solution of hydrochloric acid, which on evaporation will leave the hydrochloride as a residue. If the hydrochloride so obtained is not soluble in absolute alcohol to an extent greater than 0.1 g. per 10 cc. of alcohol, the base is ammonia.

TEST 2. ACIDS AND BASES

In the study of compounds containing only carbon, hydrogen, and oxygen it was found possible to distinguish clearly by titration between carboxylic acids and phenols, since the former as a class give very nearly their true equivalent weights on titration when phenolphthalein is used as an indicator, while the latter give poor end points and apparently high equivalent weights. The limiting equivalent weight for a carboxylic acid was set at about 400, with the assurance that few, if any, carboxylic acids would give values above that figure and few phenols or enols would give lower values. When compounds containing nitrogen also are considered, however, it is not possible to draw sharp distinctions between acidic, neutral, and basic substances. The reasons for this may be given in the form of a few examples.

Simple aliphatic amines, containing no oxygen, are definitely basic substances, and on titration give a true equivalent weight toward indicators such as methyl orange and Congo red. The basic dissociation constants for these compounds are usually between $K_b = 10^{-3}$ and $K_b = 10^{-5}$. Aromatic primary amines are much weaker as bases. The basic dissociation constants for these are about $K_b = 10^{-9}$ or $K_b = 10^{-10}$. The constant for ammonia is $K_b = 1.9 \times 10^{-5}$. Hence the effect of an aromatic nucleus on the basicity of the NH_2 group is much greater than is that of an aliphatic group. Secondary aromatic amines are therefore also weak bases. A secondary base, such as C_6H_5NHR, where R is an aliphatic group, is of approximately the same strength as $C_6H_5NH_2$; but a base such as $(C_6H_5)_2NH$ is very weak ($K_b = 10^{-13}$), since the second aromatic nucleus reduces still further the weak basicity of the primary aromatic amine. Bases of the strength of primary aromatic amines can be titrated almost completely, with Congo red or methyl orange as indicators, but the end points are poor and the equivalent weights so found are often high. A diaryl-substituted ammonia, such as $(C_6H_5)_2NH$, is titrated to such a slight extent that it is classified, on the basis of this test, as a neutral substance.

The same qualitative difference exists, then, between aromatic amines and aliphatic amines as bases, on the one hand, and between phenols and carboxylic acids as acids, on the other. Just as it is possible to distinguish between the latter pair on titration by the proper choice of an indicator, so it is possible by means of a properly chosen indicator to titrate, almost if not completely, the stronger aliphatic bases and leave the weaker aromatic bases titrated only a few per cent at the same end point. There are, in fact, very few bases known whose base constants lie in the range $K_b = 10^{-6}$ to 10^{-8}. Examples are quinine (2×10^{-7}), α-picoline (3×10^{-8}), and ethyl aminoacetic ester (9.7×10^{-8}). Nearly all of these are amphoteric or tautomeric in character, but their existence makes it dangerous to attempt a rigid classification based on their relative strengths as bases.

Correspondingly there can be no sharp line drawn between the weak aromatic bases and neutral substances. *Para*-amino ethyl benzoate ($NH_2C_6H_4CO_2C_2H_5$) is much weaker ($K_b = 10^{-12}$) than aniline ($K_b = 10^{-10}$). Substitution in the aromatic nucleus may produce slightly stronger bases or much weaker bases than the simple aromatic amine. In general, the substitution of hydrogen in the phenyl nucleus by negative groups, such as $—Cl$, $>C{=}O$, $—NO_2$, will weaken the aromatic base. For example, Michler's ketone, $[(CH_3)_2N—C_6H_4]_2CO$, is practically neutral, while *para*-chloroaniline ($Cl—C_6H_4—NH_2$) is only slightly weaker than aniline as a base.

A somewhat arbitrary definition of a basic substance has been assumed by Mulliken ("Identification of Pure Organic Compounds," Vol. II), which is the basis of Test 2a. This states that if, on titration with acid in alcohol or water solution, with Congo red paper as an outside indicator, the compound has an apparent equivalent weight of less than 1000, it is to be considered a base. The value of the test is enhanced by the fact that Mulliken has listed in the order of their boiling points or melting points a large number of liquids and solids which, according to this classification, are bases. Although Congo red and methyl orange indicators change color at nearly the same hydrogen ion concentration, the color change of Congo red is more definite, and the use of the dry indicator paper in practice leads to an end point farther on the acid side of neutral, and hence results in the detection of weaker bases.

Acidic substances containing nitrogen may contain carboxyl groups, phenolic groups, or enolic groups, or their acidity may be due to the presence of an oxime ($:NOH$), isonitro ($:NO_2H$), or acidic imine ($:NH$) group. As in the case of the bases, no sharp line can be drawn between distinctly acidic substances and very weak acids. Any compound which, on titration with alkali under the conditions specified in the test, gives at the phenolphthalein end point an apparent equivalent weight of less than 1000 will be considered an acid. In testing for the carboxyl group a limit of 400 was used (see Division I, Test 1a) in order to eliminate the phenols from consideration. A perusal of the table on page 200 will show that there are some acids which are stronger than acetic acid ($K_a = 1.8 \times 10^{-5}$) and yet contain no carboxyl group. On the other hand, some compounds, such as the amino acids, are practically neutral substances or very weak acids. Hence, for the present purpose no attempt will be made to determine by a titration procedure what type of acid is present.

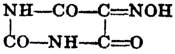
The table on pages 200 and 201 lists some typical acids containing nitrogen. Under amino acids it may be noted that if the amine group is purely aliphatic, as in the case of aminoacetic acid, the resulting compound is practically neutral. If, however, the amine group is aromatic in type, the presence of the weak base does not so completely neutralize the carboxyl group, and the compound is distinctly acidic. In a similar manner we may compare the degrees of hydrolysis of ammonium acetate and aniline acetate. The solution of the former is nearly neutral, since the degrees of hydrolysis of the ammonium and acetate ions respectively are of the same order of magnitude. The solution of the aniline acetate, however, is definitely acidic because of the greater hydrolysis of the anilonium ion. Amino acids, then, can be considered as salts; and from the relative strengths of the acidic and the basic units present predictions can be made as to their approximate strengths as acids or as bases.

In considering the remainder of the table, attention need be called only to the fact that simple oximes, nitro derivatives, nitriles, and acid amides are practically neutral in character. They usually form metallic salts and are more soluble in dilute alkali than in water, but they usually give at the phenolphthalein end point equivalent weights greater than 1000. The acidic types listed have more than one nitro group, or have an oxime group in the alpha position with respect to a carbonyl, or they are diacid amides. In other words, they have an accumulation of so-called negative groups about the ionizing hydrogen. In general, the same factors which promote enolization will raise a very weak acid to the class of distinctly acidic substances.

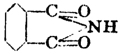
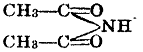
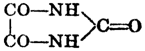
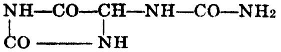
In his list of acidic compounds Mulliken (loc. cit.) includes substances of the indicator type. This is justifiable, since a change of color is associated with salt formation, so that if a change of color is produced on adding a few drops of alkali, the substance must be acidic even though no information at all is obtainable regarding an equivalent weight or its actual strength as an acid. Triacid amides hydrolyze rapidly enough to appear as acids. Certain aminophenols are oxidized in alkaline solution by atmospheric oxygen to colored substances, so that they appear among the compounds listed as acids.

In certain cases complete reliance may be placed on the numerical values of the equivalent weights obtained. This has to do with the actual base or acid strengths concerned, and

TYPES OF ACIDIC SUBSTANCES CONTAINING NITROGEN

TYPE	EXAMPLE	DISSOCIATION CONSTANT, K_a
Amino acids	Aminoacetic acid $NH_2—CH_2—CO_2H$	1.8×10^{-10} ($K_b = 2.8 \times 10^{-12}$) (Does not respond to Test 2)
	Phenylaminopropionic acid $C_6H_5NH—CH_2—CH_2—CO_2H$	4.2×10^{-6}
	Ethylaminobenzoic acid $C_2H_5NH—C_6H_4—CO_2H$	8×10^{-6}
	Picolinic acid $C_5H_4N—CO_2H$	5×10^{-6}
	m-Aminobenzoic acid $NH_2—C_6H_4—CO_2H$	1.6×10^{-5}
Nitro acids	2, 5 Dinitrobenzoic acid $(NO_2)_2C_6H_3—CO_2H$	2.6×10^{-2}
Aminophenols	*p*-Aminophenol $NH_2—C_6H_4—OH$	Basic
Nitrophenols	*p*-Nitrophenol $NO_2—C_6H_4—OH$	6×10^{-8}
	3, 4 Dinitrophenol $(NO_2)_2C_6H_3—OH$	4×10^{-6}
Nitro compounds . . .	Nitromethane $CH_3—NO_2$	1×10^{-11} (Does not respond to Test 2)
	Nitroethane $CH_3—CH_2—NO_2$	Less than 1×10^{-10} (Does not respond to Test 2)
	Dinitroethane $CH_3—CH(NO_2)_2$	5.8×10^{-6}
	Methyl nitroamine $CH_3—NH—NO_2$	7×10^{-7}
	Phenyl nitroamine $C_6H_5—NH—NO_2$	2.3×10^{-5}
Oximes and nitrolic acids and hydroxamic acids .	Benzophenone oxime $(C_6H_5)_2C{=}NOH$	Less than 1×10^{-10} (Does not respond to Test 2)
	Acetoxime $(CH_3)_2C{=}NOH$	5×10^{-13} (Does not respond to Test 2)
	Isonitrosopropylmethyl ketone $CH_3—CO—C(:NOH)—C_2H_5$	3.1×10^{-10} (Yellow salts)
	Isonitrosoacetone $CH_3—CO—CH(:NOH)$	3.8×10^{-9} (Yellow salts)
	Violuric acid 	2.7×10^{-5} (Colored salts)
	Ethyl nitrolic acid $CH_3C(:NOH)NO_2$	6×10^{-9} (Red salts)
	Propionhydroxamic acid $CH_3—CH_2—C(:NOH)OH$	3×10^{-8}
	Benzhydroxamic acid $C_6H_5C(:NOH)OH$	7×10^{-7}

TYPES OF ACIDIC SUBSTANCES CONTAINING NITROGEN (CONTINUED)

TYPE	EXAMPLE	DISSOCIATION CONSTANT, K_a
Acid amides and cyanides	Acetamide $CH_3—CO—NH_2$	1×10^{-15} (Does not respond to Test 2)
	Phthalimide 	5×10^{-9} (Does not respond to Test 2)
	Methyl cyanide $CH_3—CN$	Neutral
	Diacetamide  $(CH_3—C{=}O)_2{>}NH$	(Does not respond to Test 2)
	Triacetamide $(CH_3—C{=}O)_3N$	Hydrolyzes rapidly
	Acetyl phthalimide $C_6H_4(:CO)_2:N—CO—CH_3$	Hydrolyzes rapidly
	Cyanuric acid $C_3H_3O_3N_3$	1.8×10^{-7}
	Oxalylurea  $(CO—NH)_2{>}C{=}O$	7.5×10^{-7}
	Xanthine $C_5H_4O_2N_4$	1.2×10^{-10} (Does not respond to Test 2)
	Uric acid $C_5H_4O_3N_4$	1.5×10^{-6}
	Allantoin  $NH—CO—CH—NH—CO—NH_2$; $CO—NH$	1.2×10^{-9}
	Benzoyl cyanamide $C_6H_5CO—NH—CN$	2×10^{-3}
	Hydrocyanic acid HCN	7.2×10^{-7}

information concerning these may be had by a comparison of the equivalent weights obtained at different end points. For instance, any base which gives an equivalent weight less than 1000 to the phenolphthalein end point is certain to titrate completely at the Congo red or methyl orange end point. Correspondingly, an acid which gives an equivalent weight toward Congo red or methyl orange of less than 1000 will titrate completely at the phenolphthalein end point. In this connection sharpness of the end point is a valuable criterion of the accuracy of the numerical result obtained.

In the case of salts definite information regarding the nature of the acid and base constituents may be obtained by titration with different indicators. The anion of any weak acid is a potential base, and the various substituted ammonium ions are all acidic. Any salt of a base as weak as aniline ($K_b = 10^{-10}$) will titrate as an acid to phenolphthalein, provided the acid concerned in the salt would itself be titratable at the same end point. A salt of a base as strong as ammonia ($K_b = 10^{-5}$) would titrate incompletely as an acid and give a poor end point to phenolphthalein. The salt of a strong acid (hydrochloric etc.) would not appear basic to the Congo red end point. The salt of a moderately weak acid, such as acetic, would be definitely basic at the Congo red end point, although the apparent equivalent weight might be as high as 1500 and the end point very poor. If in this case the equivalent weight at the Congo red end point were compared with the equivalent weight obtained by using an indicator changing at a hydrogen ion concentration of 10^{-2} or 10^{-3} equivalents per liter (methyl violet), very direct evidence of the presence of the anion of a weak acid would be obtained. If, however, the end points to Congo red and methyl violet differed no more than in pure water or sodium chloride solution, the conclusion could be drawn that the acid of the salt was a strong acid.

Similarly, an indicator changing far on the basic side (trinitrobenzene) could be compared with phenolphthalein. Aniline salts of strong acids would give nearly the same equivalent weight at the two end points, since at both points they are titrated completely, but aliphatic amine salts would give widely different results at the two end points. Reference should be made to the titration curves given in Part IV, p. 259, as an aid in determining the behavior of salts of a given type on titration.

Any salt which in solution requires more acid or base to reach a given end point than does the corresponding volume of pure water may be considered to be the salt of a weak acid or of a weak base respectively.

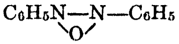
Test 2. Dissolve or suspend 0.1 g. of the liquid or finely divided solid in 10 cc. of water and add decinormal alkali, drop by drop, until about 0.5 cc. has been added. If a change of color occurs, add more of the alkali slowly. If the change of color is progressive over 1 cc., the substance has acidic properties and the color is not due to the presence of traces of impurities. If no appreciable color appears, add phenolphthalein indicator and continue the titration. Where the indicator can be used, more than 1 cc. of alkali is necessary to show a positive test for acid properties, or the calculated equivalent weight must be less than 1000. The end point taken should be an easily perceptible pink coloration that is stable for at least half a minute, with constant stirring if the substance did not dissolve in water. When the end point is reached, add decinormal acid to decolorize the phenolphthalein; then add methyl orange indicator and continue the titration with acid. Note carefully the volume of acid used at the yellow-orange and the orange-red end points as a criterion of the sharpness of the end point. Subtract from the total number of equivalents of acid used the number of equivalents of alkali which was first added. If the result is positive (more acid than base used) to an extent greater than 1 cc., the substance is basic; if it is negative, the substance is an acid strong enough to affect methyl orange.

Repeat the titration with 1.0 *N* acid, using a fresh 0.5-gram sample and Congo red indicator paper as an outside indicator. This is done by touching the paper with the moist stirring rod from time to time and adding acid until a permanent blue coloration results. When the end point is reached, add methyl violet indicator and continue the titration with acid to a blue end point. Compare the behavior of the same volume of dilute sodium chloride solution between the same Congo red and methyl violet end points. If the solution of the substance at the Congo red end point gives an apparent equivalent weight much greater than that calculated for the methyl violet end point when corrected for the blank experiment on the salt solution, the substance is a very weak base or the salt of a weak acid. A compound which gives a calculated equivalent weight of less than 1000 when titrated to the Congo red end point will be found classified in Mulliken's "Identification of Pure Organic Compounds" as a basic substance.

TEST 3. NITRO, NITROSO, AZO, AND AZOXY COMPOUNDS, NITRITES, AND NITRATES

The types of substances hitherto considered which rapidly reduce Tollen's reagent at room temperature include the aldehydes, simple carbohydrates, and some polyhydric phenols. There are three classes of substances containing nitrogen which are also readily oxidized by Tollen's reagent:* namely, hydroxylamines of the type RNHOH, hydrazines of the type R—NH—NH—R, and *ortho* and *para* aminophenols. Substances dealt with in this test do not reduce Tollen's reagent, but if they are subjected to reduction by zinc in neutral solution, either hydroxylamines or hydrazines are formed, as shown in the table. The plan of Test 3a, therefore, is first to ascertain the absence of aldehydes, polyhydric phenols, aminophenols, hydroxylamines, and hydrazines, and then to determine whether any of these substances can be formed by neutral reduction. We may list these types of substances and their reduction products.

PRODUCTS OF THE NEUTRAL REDUCTION OF SOME NITROGEN COMPOUNDS

TYPE OF SUBSTANCE	FORMULA	PRODUCT OF NEUTRAL REDUCTION BY ZINC DUST
Aromatic nitro compounds	$C_6H_5NO_2$	C_6H_5NHOH or $HOC_6H_4NH_2$
Aliphatic nitro compounds .	RNO_2	$RNHOH$
Aromatic nitroso compounds	C_6H_5NO	C_6H_5NHOH or $HOC_6H_4NH_2$
Azo compounds	$C_6H_5N{=}NC_6H_5$	$C_6H_5NH{-}NHC_6H_5$
Azoxy compounds	 $C_6H_5\underset{\diagdown O\diagup}{N{-}N}{-}C_6H_5$	$C_6H_5NH{-}NHC_6H_5$
Nitrosoamines	$R_2N{-}NO$	$R_2N{-}NHOH$ or H_2NOH
Nitroamines	$R_2N{-}NO_2$	$R_2N{-}NHOH$ or H_2NOH
Nitrite ester	$RONO$	H_2NOH
Nitrate ester	$RONO_2$	H_2NOH

If one of the above classes of substances is present, further tests must be made, to determine which one. The first test applied (Test 3b) serves to distinguish aromatic nitro and nitroso compounds and azo and azoxy compounds from the rest and from each other. Alkaline reduction with zinc dust is the reaction used, and the product in each case is a diaryl-substituted hydrazine or hydrazo compound. These are colorless substances readily oxidized in alkaline solution by oxygen gas to colored azo compounds.† The reactions are shown on the opposite page.

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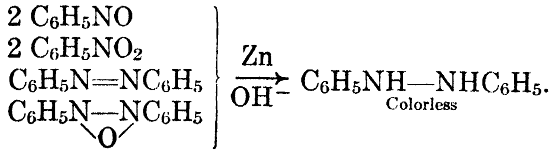
* This of course presumes the absence of aldehyde groups in other types of nitrogen-containing compounds.

† Many organic compounds become colored when heated in alkaline solution in the presence of air. Aldehydes give aldehyde resins, polyhydric phenols give quinhydrones, and *ortho* and *para* diamines and aminophenols give similar oxidation products. These substances are excluded by Test 3a.



$$\left.\begin{array}{l} 2\ C_6H_5NO \\ 2\ C_6H_5NO_2 \\ C_6H_5N{=}NC_6H_5 \\ C_6H_5N{-}NC_6H_5\ (\text{bridged by } O) \end{array}\right\} \xrightarrow[OH^-]{Zn} \underset{\text{Colorless}}{C_6H_5NH{-}NHC_6H_5}.$$

$$\underset{\text{Colorless}}{C_6H_5NH{-}NHC_6H_5} \xrightarrow[OH^-]{O_2} \underset{\text{Colored}}{C_6H_5N{=}NC_6H_5}.$$

If the colorless solution which is formed in the absence of air gives a color when exposed to air and warmed, the original compound must belong to one of the four types above. Should the compound formed upon reoxidation have the properties of the original, as tested by color in acid and alkaline solution and by other properties, the original must have been an azo compound. Of the remaining three types of compounds, the nitroso derivatives can be distinguished by their color, which is usually green or blue in solution or in the molten state. The azoxy compounds possess a characteristic yellow color, but this cannot be used to distinguish them from the aromatic nitro compounds, since many members of the latter class are also yellow.

To differentiate further between the various classes of substances detected in Test 3a, advantage is taken of the fact that certain of these readily yield nitrous or nitric acid in the presence of strong acids, and that these acids can easily be detected by Liebermann's nitroso reaction. The types of compounds giving this reaction are tabulated below:

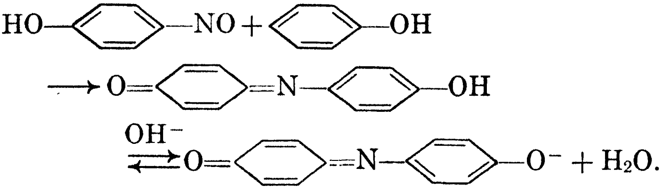
THE HYDROLYSIS PRODUCTS OF SOME DERIVATIVES OF NITROUS AND NITRIC ACIDS

TYPE OF COMPOUND	HYDROLYSIS PRODUCT IN CONCENTRATED H_2SO_4
$R_2N{-}NO$	$R_2NH \cdot H_2SO_4 + HNO_2$
$R_2N{-}NO_2$	$R_2NH \cdot H_2SO_4 + HNO_3$
$RONO$	$RHSO_4 + HNO_2$
$RONO_2$	Aldehyde or ketone + HNO_2 or $RHSO_4 + HNO_3$
$R_3C{-}NO_2$	$R_3C{-}HSO_4 + HNO_2$

Under the conditions of the test (concentrated sulphuric acid and phenol mixture) some of the nitric acid is reduced to nitrous acid, so that nitrous acid is present in all these cases and it reacts with the phenol to form *para*-nitrosophenol:

$$HONO + C_6H_5OH \longrightarrow ON—C_6H_4—OH + H_2O.$$

This in turn condenses in concentrated sulphuric acid with another molecule of phenol to yield compounds of the indophenol type:

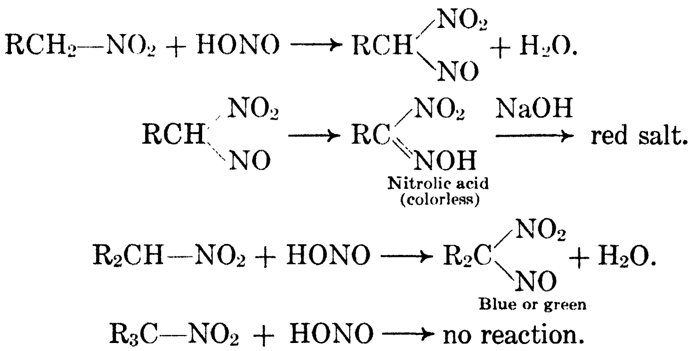


In the concentrated sulphuric acid solution the indophenol is blue, in dilute acid it is red, and in alkali it is again blue. Hence a blue or green color in dilute alkaline solution as a result of this series of reactions indicates the presence of a compound which readily hydrolyzes to give nitrous or nitric acid. Compounds containing nitro or nitroso groups attached to carbon seldom hydrolyze to form nitrous acid. However, some tertiary aliphatic nitro compounds and aromatic nitro compounds in which two of the positions *ortho* and *para* to the group in question are occupied by sulphonic acid groups or by other nitro groups, yield nitrous acid under the conditions of Test 3c. The nitrosophenols, of course, give the color reaction without the intermediate production of nitrous acid, and on longer heating *para*-nitrophenols and *para*-nitrosoamines give similar condensation reactions which result in colors varying from yellow to green or blue. Hence a positive result in Test 3b for aromatic nitro or nitroso compounds may render useless the application of Test 3c.

Test 3d depends upon the reaction of aliphatic nitro compounds with nitrous acid. Hydrogen on a carbon atom which is in the alpha position with respect to a nitro group is even more reactive than in the corresponding position with respect to a carbonyl group. This reactivity results in a marked tautomerism which gives the substance the property of a weak acid.

$$\underset{\text{Colorless, insoluble}}{R{-}CH_2{-}NO_2} \rightleftharpoons \underset{\text{Colorless or slightly yellow}}{R{-}CH{=}NO_2H} \overset{NaOH}{\rightleftharpoons} \underset{\text{Colorless or slightly yellow}}{R{-}CH{=}NO_2Na} + H_2O.$$

The structures of the ions are not definitely known. Nitrous acid reacts upon an aliphatic nitro compound as follows:



$$RCH_2{-}NO_2 + HONO \longrightarrow RCH\begin{matrix}\diagup NO_2\\ \diagdown NO\end{matrix} + H_2O.$$

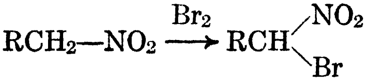
$$RCH\begin{matrix}\diagup NO_2\\ \diagdown NO\end{matrix} \longrightarrow \underset{\text{Nitrolic acid (colorless)}}{RC\begin{matrix}\diagup NO_2\\ \diagdown\!\!\diagdown NOH\end{matrix}} \xrightarrow{NaOH} \text{red salt.}$$

$$R_2CH{-}NO_2 + HONO \longrightarrow \underset{\text{Blue or green}}{R_2C\begin{matrix}\diagup NO_2\\ \diagdown NO\end{matrix}} + H_2O.$$

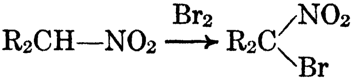
$$R_3C{-}NO_2 + HONO \longrightarrow \text{no reaction.}$$

The reaction product of a secondary aliphatic nitro compound with nitrous acid has no acidic hydrogen and therefore it does not react with alkali.

The formation of the red salts of the nitrolic acids is not strictly reversible. The structures of the salts and acids are not definitely known. Both the salts and the acids readily undergo intramolecular oxidation and reduction, giving rise to aldehydes (or ketones), acids, hydroxylamine, or nitrous oxide, N_2O. The conditions for successful application of the test are therefore limited. There is no specific positive test for the tertiary aliphatic nitro compounds. Given the fact that a substance is an aliphatic nitro compound, the test for acidity (solubility in alkali or salt formation) serves to distinguish the tertiary from the primary and secondary compounds. The above color test may serve to distinguish between the primary and secondary, or, as an alternative, the compound may be treated with one mol of bromine.



Soluble in alkali



Insoluble in alkali

The monobromo derivative of a primary nitro compound will possess the possibility of tautomerism, and hence will display acidic properties, while the secondary nitro compound will be neutral.

Nitro and nitroso groups are commonly found in the same molecule with other groups, and the substance is usually examined further to complete its classification. Acidic and basic properties of the compounds falling under Test 3a may have been discovered, provided the compound in question conformed to the limiting conditions of Test 2.

It may be possible in certain cases to perform Tests 3b, 3c, and 3d upon a compound which reduces Tollen's reagent. In such cases the cause for the reaction with Tollen's reagent must first be ascertained, and some consideration given to the possibility of obtaining ambiguous results, owing to the presence of the two or more groups in the same hydrocarbon nucleus.

Test 3a. This test depends upon the reduction of the unknown to a hydrazine, a hydroxylamine, or an aminophenol, all of which reduce Tollen's reagent.

Test a solution of the substance in 50 per cent alcohol with Tollen's reagent in the cold. If immediate reduction of the silver ion occurs, determine what groups present give the reaction, and consult the instructor as to the possibility of applying the specific tests 3b, 3c, and 3d to the substance. A rapid reaction between the original substance and Tollen's reagent precludes the possibility of applying the general test 3a.

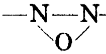
If no immediate reduction of silver ion is observed, treat a solution of the substance in 50 per cent alcohol with a little solid calcium chloride and an excess of zinc dust. Boil it to start the reaction, allow it to stand for five minutes, filter, and add the filtrate to the silver solution. A dark precipitate of metallic silver which forms only after the treatment with zinc indicates the presence of a nitro, nitroso, azo, or azoxy compound, a nitrite, or a nitrate.[*]

Test 3b. Aromatic azo, azoxy, nitro, and nitroso compounds. Reduce some of the substance in a 1 *N* solution of alkali in 80 per cent alcohol with zinc dust until an almost colorless solution is obtained. Use a small sample and heat the mixture in a *loosely* stoppered test tube with constant shaking until an almost colorless solution[†] is obtained. Decant it from the precipitate and blow air through the hot solution. If the color of the original substance is regenerated (compare in both alkaline and acid solutions), the substance is an azo compound. If a different color is formed, the substance is an aromatic nitro or nitroso compound or an azoxy compound.

Test 3c. *N*-nitrosoamine, *N*-nitroamine, nitrate, nitrite, and tertiary aliphatic nitro compounds. Dissolve 0.2 g. of the substance with an equal quantity of phenol in 1 cc. of concentrated sulphuric acid and pour the mixture into 50 cc. of water. Add an excess of sodium hydroxide. A blue or green color indicates the presence of an $>N{-}NO$, $>N{-}NO_2$, $-O{-}NO$, or $-O{-}NO_2$ group, or a tertiary aliphatic nitro body.

Test 3d. Primary and secondary aliphatic nitro compounds. Dissolve about 0.1 g. of the unknown in 6 *N* sodium hydroxide and add two drops of a saturated solution of sodium nitrite. Carefully neutralize the solution with dilute (1 *N*) sulphuric acid, and then make it alkaline with sodium hydroxide. A red color indicates a primary aliphatic nitro body, that is, the group $-CH_2NO_2$; a blue color indicates a secondary aliphatic nitro body, that is, the group $>CHNO_2$.

Test 3e. Nitroso and amino compounds, nitro acids, nitrolic acids, nitrophenols, aryl polynitro compounds, and nitrosophenols. If the original substance when heated (or a hot solution of it) acquires a blue or green color, it is probably a nitroso compound.

If the substance is of a basic character, it contains an amino group in addition to $-NO_2$, $-NO$, $-N{=}N-$, or  $-N\underset{O}{-}N-$. Green bases which form yellow or orange salts are nitroso compounds of aromatic amines. If the substance is of an acidic nature, it is a primary or secondary aliphatic nitro body, a nitro amine, a nitrolic acid, a nitrophenol, a polynitro aromatic compound, or an acid or phenol having an —NO, $-NO_2$, —N=N—, or $-\underset{\diagdown O \diagup}{N-N}-$ group.

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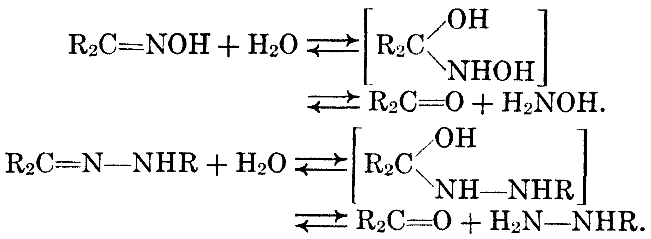
[*] An acid amide, phthalimide, has been found to produce a silver precipitate with Tollen's reagent after treatment with zinc dust in either neutral or alkaline solution.

[†] If difficulty is encountered in obtaining a colorless solution, start again with a smaller sample and use ammonium hydroxide instead of sodium hydroxide as the alkali.

TEST 4. OXIMES, HYDRAZONES, OSAZONES

Hydrazones and oximes are substituted imines and as such have the general structure $R_2C=N-$. Rupture of the molecule at the point of the double bond proceeds readily as a result of displacement of the following equilibria:



$$R_2C=NOH + H_2O \rightleftarrows \left[R_2C\begin{matrix} \diagup OH \\ \diagdown NHOH \end{matrix} \right] \rightleftarrows R_2C=O + H_2NOH.$$

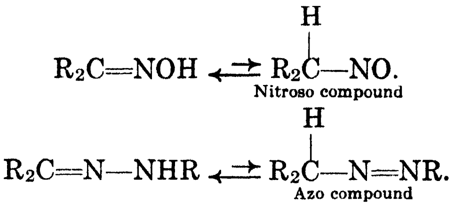
$$R_2C=N-NHR + H_2O \rightleftarrows \left[R_2C\begin{matrix} \diagup OH \\ \diagdown NH-NHR \end{matrix} \right] \rightleftarrows R_2C=O + H_2N-NHR.$$

The brackets indicate the intermediate addition product as hypothetical. Strong acids almost completely remove the free bases H_2NOH and $RNHNH_2$ as the ions H_3NOH^+ and $RNH_2-NH_2{}^+$ respectively, and hence the hydrolysis in strong acid goes to completion:

$$R_2C=NOH + H_2O + H^+ \longrightarrow R_2C=O + NH_3OH^+.$$

The reaction of hydrolysis is slow at room temperature. It is probable that besides shifting the equilibrium, H+ also increases the rate of hydrolysis.

Other tautomeric forms of the oximes and of the hydrazones exist in too small concentration to be detected by ordinary means:



$$R_2C=NOH \rightleftarrows R_2\overset{H}{\overset{|}{C}}-NO.$$

Nitroso compound

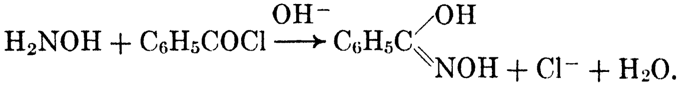
$$R_2C=N-NHR \rightleftarrows R_2\overset{H}{\overset{|}{C}}-N=NR.$$

Azo compound

The existence of geometric isomers does not complicate the reaction, since in any case both isomers give the same hydrolysis products.

Tests 4a and 4b depend upon the detection of hydroxylamine or a hydrazine present as a result of hydrolysis. Reference to the discussion of Test 3 will make unnecessary here any further comment on the use of Tollen's reagent as a means of detecting these substances in the absence of aldehydes. The compound to be tested is first treated with Tollen's reagent to show the absence of —NHOH, —NH—NH—, and —CHO groups. It is then subjected to hydrolysis in a bomb tube, and then the solution is evaporated to dryness. In most cases any aldehydes formed by hydrolysis would evaporate, leaving only the salt of a base. If this salt reduces Tollen's solution, it is a salt of hydroxylamine or of a monosubstituted hydrazine. If for any reason it is suspected that other organic matter capable of reducing Tollen's reagent remains after the evaporation, the procedure of Test 4b should be followed, which allows actual isolation of the hydrazine derivative.

A salt found to reduce Tollen's reagent may be one either of hydroxylamine or of a hydrazine. To distinguish them, benzhydroxamic acid is prepared by the reaction

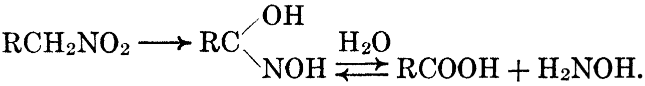


$$H_2NOH + C_6H_5COCl \xrightarrow{OH^-} C_6H_5C\begin{matrix}\diagup OH \\ \diagdown NOH\end{matrix} + Cl^- + H_2O.$$

This substance gives, with ferric ion, the reddish purple color characteristic of the test for enols (p. 151) and hydroxamic acids. The appearance of such a color is evidence of the presence of hydroxylamine salt and hence of an oxime. There is no delicate specific test for hydrazines. As bases most of them may be extracted with ether from an alkaline solution, but not from an acid solution. Hydroxylamine is not soluble in ether in the presence of water.

The hydrolysis may at times be as well accomplished under a reflux condenser as in a bomb tube. Arylhydrazines and arylosazones are subject to oxidation by the air on prolonged heating, however, and the bomb tube prevents access of air.

Some primary and secondary aliphatic nitro compounds undergo intramolecular oxidation and reduction, yielding hydroxylamine derivatives, which in turn give hydroxylamine on hydrolysis:



$$\mathrm{RCH_2NO_2} \longrightarrow \mathrm{RC}\begin{matrix}\mathrm{OH} \\ \mathrm{NOH}\end{matrix} \overset{\mathrm{H_2O}}{\rightleftharpoons} \mathrm{RCOOH} + \mathrm{H_2NOH}.$$

This reaction usually takes place only when the nitro compound has been dissolved in alkali and the solution then treated, when warm, with an excess of strong acid. A nitro compound would be detected normally under the procedure outlined in Test 3a.

Test 4a. If the substance does not reduce Tollen's reagent, heat about 2 g. of it with 3 cc. of 12 *N* hydrochloric acid for half an hour at 100° in a sealed tube. Cool the tube, open it, dilute the contents with two volumes of water, and evaporate to dryness on the steam bath. Take up the residue in water and test a portion with Tollen's reagent in the cold. A reduction shows the presence of a hydrazine or of hydroxylamine in the residue. These two possibilities may be distinguished by the method outlined in the next paragraph.

To the rest of the solution add about 2 g. of sodium acetate and a drop of benzoyl chloride and shake the mixture for a minute. Then add a few drops of dilute ferric chloride and four drops of 12 *N* hydrochloric acid. A reddish purple color indicates benzhydroxamic acid, which must have been derived from hydroxylamine. The presence of hydroxylamine after hydrolysis indicates an oxime, while the formation by hydrolysis of a reducing agent which is not hydroxylamine shows the presence of a hydrazone or of an osazone containing the group $>\mathrm{C{=}N{-}NH}{-}$.

Test 4b. If the original substance reduces Tollen's reagent, perform the hydrolysis of Test 4a, using larger quantities, and, after the hydrolysis, extract the acid solution with ether. This ethereal extract should be examined for ketones and aldehydes. The aqueous layer is made strongly alkaline with sodium hydroxide and extracted with ether. This ether solution can now be tested for a hydrazine with Tollen's reagent, and in fact the hydrazine can be isolated by drying the ethereal solution with solid potassium carbonate and evaporating off the ether. If this product is not the original substance, the latter was a hydrazone or an osazone.

If the original substance reduces Tollen's reagent, Test 4b must be used to indicate a hydrazone; however, under the same circumstances Test 4a is still applicable as a means of testing for an oxime, since hydroxylamine may be detected as a hydrolysis product without the use of Tollen's reagent.

TEST 5. PRIMARY AMINES, PRIMARY HYDRAZINES, AMINO ACIDS, AND PRIMARY AMIDES

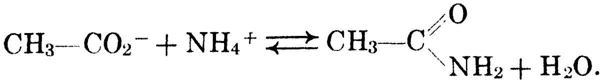
Primary amines are characterized by the $—NH_2$ group. Although the compounds containing this group vary widely in physical and in some chemical properties, they are similar in that, with few exceptions, they give nitrogen gas on treatment with nitrous acid:

$$RNH_3^+ + HNO_2 \longrightarrow ROH + N_2 + H_2O + H^+.$$

The above equation expresses the view that the amine in acid solution (substituted ammonium ion) reacts with undissociated nitrous acid. This is based on the fact that the reaction rate is catalyzed by acid but is independent of an acid concentration greater than that necessary to convert the amine to the substituted ammonium ion and nitrite ion to nitrous acid.

Another view is that the nitrite salt of the amine changes reversibly into the corresponding amide, as do ammonium salts of carboxylic acids:

$$NO_2^- + RNH_3^+ \rightleftharpoons RNH—NO + H_2O.$$



$$CH_3—CO_2^- + NH_4^+ \rightleftharpoons CH_3—C\begin{matrix}{}^{\nearrow O} \\ {}_{\searrow NH_2}\end{matrix} + H_2O.$$

$$\begin{aligned} CO_3^{--} + 2\,NH_4^+ &\rightleftharpoons NH_4^+ + NH_2—CO_2^- + H_2O \\ &\rightleftharpoons (NH_2)_2CO + 2\,H_2O. \end{aligned}$$

These reactions are catalyzed by H^+ and in the case of most carboxylic acids take place rapidly only at high temperatures. The last requires several weeks to come to equilibrium at 25°, whereas the first requires but a few seconds in most cases. The evidence for this step is that in the case of secondary amines the so-called nitrosoamine is a stable product:

$$R_2NH_2^+ + NO_2^- \longrightarrow R_2N—NO + H_2O.$$

In the case of the primary amine the amide (or nitroso) derivative rapidly tautomerizes:

$$RNH—NO \rightleftarrows RN{=}NOH.$$

The equilibrium favors the diazo hydroxide form, which in the case of many aromatic derivatives can be isolated, but which in the case of most aliphatic derivatives is very unstable: *

$$RN{=}NOH \longrightarrow ROH + N_2.$$

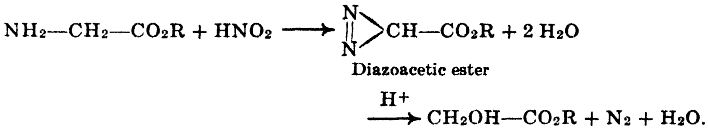
The aromatic diazo hydroxides are known to ionize as ampholytes:

$$H^+ + C_6H_5N_2O^- \rightleftarrows C_6H_5N_2OH \rightleftarrows C_6H_5N_2{}^+ + OH^-.$$

The ions of various acids can therefore be substituted for the OH^- ions, and the stabilities of the various products will depend upon their degrees of ionization, solubility, tendency to rearrange, and tendency to lose nitrogen gas. The following table gives a few of the known types of compounds:

ACID	DIAZO COMPOUND
H_2O	$C_6H_5N_2OH$
HCl	$C_6H_5N_2Cl$
HCN	$C_6H_5N_2CN$
C_2H_5OH	$C_6H_5N_2OC_2H_5$
C_6H_5OH	$C_6H_5N_2OC_6H_5$
$C_6H_5NH_2$	$C_6H_5N_2NHC_6H_5$

* The alcohol formed is not always the one expected on the basis of direct replacement of the —NH_2 group by OH. For instance, from *n*-propylamine, $CH_3—CH_2—CH_2—NH_2$, considerable isopropyl alcohol, $CH_3—CHOH—CH_3$, is obtained. Many similar instances indicate that the decomposition of the diazo hydroxide is not a simple replacement reaction but involves intramolecular condensations leading to heterocyclic rings. A fairly stable aliphatic diazo compound is obtained from an α-amino ester:



$$NH_2—CH_2—CO_2R + HNO_2 \longrightarrow \begin{array}{c}N\\ \|\\ N\end{array}\!\!>CH—CO_2R + 2\,H_2O$$

Diazoacetic ester

$$\xrightarrow{H^+} CH_2OH—CO_2R + N_2 + H_2O.$$

Berk and Hermann (*Chem. Weekblad*, 22, 270–272 (1925)) assume intermediate ring derivatives as follows, where the dotted lines in the bracketed formula indicate

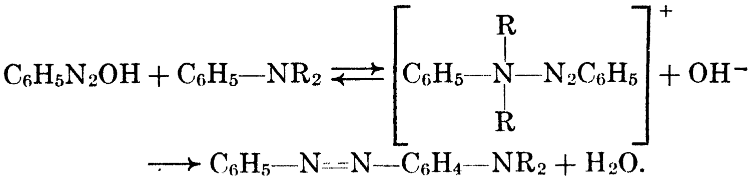
The un-ionized molecules have diazo structures such as $C_6H_5-N=N-NH-C_6H_5$, and the positive ion a diazonium structure, $C_6H_5-N^+\equiv N$. Increased hydrogen ion concentration favors the latter according to the above equilibrium. Since the so-called coupling reactions take place readily only in dilute acid or in alkali, it is assumed that the diazo rather than the diazonium form is involved in such reactions.

The last two members of the table on page 214 are of particular interest because of their tendency to rearrange (Hofmann rearrangement of substituted aromatic amines).

$$C_6H_5-N=N-OC_6H_5 \longrightarrow C_6H_5-N=N-C_6H_4OH,$$

$$C_6H_5-N=N-NHC_6H_5 \xrightarrow{H^+} C_6H_5-N=N-C_6H_4NH_2.$$

The resulting products are highly colored stable substances of the azo type. Similarly constituted aliphatic compounds, $RN=NR$, are known, but they are not prepared by similar reactions. The condensation of a tertiary aromatic amine with a diazo compound is believed to proceed through the formation of an intermediate compound of the quaternary type which then undergoes rearrangement.



$$C_6H_5N_2OH + C_6H_5-NR_2 \rightleftarrows \left[C_6H_5-\overset{\displaystyle R}{\underset{\displaystyle R}{N}}-N_2C_6H_5\right]^+ + OH^-$$

$$\longrightarrow C_6H_5-N=N-C_6H_4-NR_2 + H_2O.$$

Test 5a is a general test dependent upon the decomposition of the diazotized $-NH_2$ group into nitrogen gas. The reaction is carried out in an atmosphere of CO_2 gas. The nitrogen is

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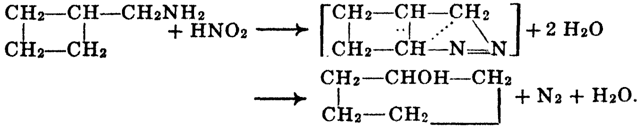
respectively the bond which is broken and the bond which is formed when the final product is produced:

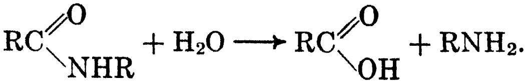


The substitution of nitrogen in diazo compounds by the use of cuprous salts (Sandmeyer reaction) also suggests the formation of complex intermediate products, collected, freed from nitric oxide, and measured. The production and absorption of the nitric oxide take place according to the equations

$$3\,HNO_2 \longrightarrow 2\,NO + HNO_3 + H_2O,$$
$$NO + MnO_4^- \longrightarrow NO_3^- + MnO_2.$$

Small quantities of nitrogen dioxide, NO_2, are formed, but this gas is absorbed by the potassium hydroxide solution used to remove carbon dioxide. Too great an excess of nitrite is to be avoided because of the large volume of nitric oxide which may be formed. The production of nitrogen is not quantitative, but the procedure in some cases, particularly those of aliphatic amines, can be made to yield results within 1 per cent of the theoretical value. If we calculate from the volume of nitrogen produced an equivalent weight for the amine, and this proves to be below 500, we may assume that the compound tested contains a primary amine group. A yield of nitrogen amounting to 40 cc. per gram of sample, measured under standard conditions, indicates an equivalent weight of 560. Some anomalies are to be noted. *Ortho* and *para* hydroxy amines and diamines condense so rapidly to form stable azo derivatives that little or no nitrogen is evolved. Urea and guanidine give about one half and one sixth of their total nitrogen respectively as nitrogen gas. Cyanates do not hydrolyze to ammonia rapidly enough to appear under the test. Some aromatic amines, such as benzidine, yield more nitrogen than corresponds to the total amount of primary amine present. This is due to the fact that the phenol produced by the diazo reaction acts as a reducing agent upon the excess nitrous acid, liberating nitrogen. Ammonia and ammonium salts react as primary amines in Test 5a.

Primary acid amides yield nitrogen upon treatment with nitrous acid. Secondary acid amides and substituted imines may yield nitrogen even though they do not contain a primary amine group, since they often hydrolyze under the conditions of the test to yield a primary amine:



$$RC{\overset{\displaystyle /\!\!/ O}{\underset{\displaystyle \diagdown NHR}{}}} + H_2O \longrightarrow RC{\overset{\displaystyle /\!\!/ O}{\underset{\displaystyle \diagdown OH}{}}} + RNH_2.$$

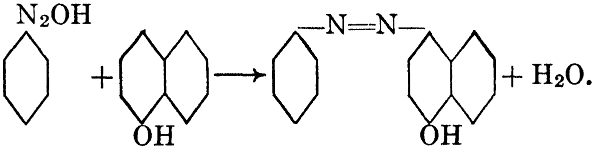
$$R_2C{=}NR + H_2O \longrightarrow R_2C{=}O + RNH_2.$$

Hexamethylenetetramine will react as a primary amine since it readily hydrolyzes in acid solution to ammonia and formaldehyde.

Test 5b for hydrazines and hydroxylamines will detect only those derivatives containing the groups —NH—NH— and —NH—OH, since further substitution prevents rapid oxidation by Tollen's solution and Fehling's solution. Most aldehydes do not affect Fehling's solution rapidly at room temperature.

Test 5c for amino acids makes use of a high-temperature intramolecular condensation to pyrrol derivatives. These in turn condense with the phenols in pine wood to give highly colored substances. Pyrrol and its derivatives are also produced from the ammonium salts of many organic acids under the conditions of this test.

In Test 5d a diazotized primary aromatic amine is condensed with a phenol to give an azo dye. The following example is typical:



When properly carried out, no color is produced during the diazotization (the diazonium compounds are nearly colorless) and no marked color nor a precipitate should appear immediately on adding alkali alone to the diazotized solution. The formation of color during diazotization is due either to the coupling of the diazotized portion of the amine with unchanged amine or to the formation of a colored nitroso compound such as the salt of *para*-nitrosodimethylaniline. Such reactions are discussed under Test 6. If the addition of alkali in the cold to the colorless diazotized material produces an immediate color in the solution or a colored precipitate, the diazotization was incomplete and the diazo compound has coupled with the excess of the free amine:

$$C_6H_5\text{—N=N—OH} + C_6H_5NH_2 \longrightarrow C_6H_5\text{—N=N—NH}C_6H_5 + H_2O.$$

Test 5a. In a small flask fitted with a dropping funnel (Fig. 32) and two delivery tubes, one of which goes to the bottom and is supplied with a screw clamp, while the other, also fitted with a clamp, is connected to a nitrometer tube containing 40 per cent potassium hydroxide solution, place a weighed amount of the unknown (about 0.1 g.) and 3 cc. of 6 *N* hydrochloric acid. Pass carbon dioxide through the apparatus until all the air is expelled, as shown by the complete absorption, by the alkali, of the issuing gas. Then add through the dropping funnel an ice-cold solution of sodium nitrite containing about 0.3 g. of sodium nitrite in 5 cc. of water. Warm the solution on a water bath and maintain a slow stream of carbon dioxide as long as gas collects in the nitrometer. Force the gas into an absorption pipette filled with a solution containing 5 per cent of potassium permanganate and 2.5 per cent of sodium hydroxide, and shake the pipette as long as absorption takes place. Measure the gas and record the temperature and pressure. More than 40 cc. of gas from a gram of the unknown indicates the presence of the group NH_2 or of some compound easily hydrolyzed to give this group. Calculate an equivalent weight for the substance.

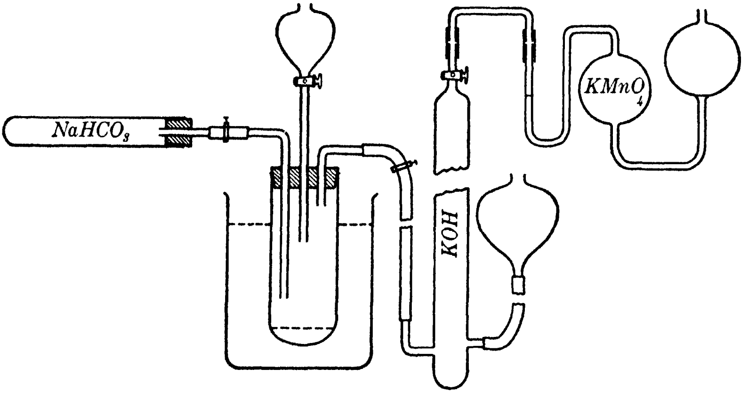


FIG. 32

Test 5b. Primary hydrazines and hydroxylamines. Add 0.1 g. of the substance to Fehling's solution. The formation of a red precipitate without heating indicates a primary hydrazine or a hydroxylamine.

Test 5c. Amino acids. Heat the unknown with zinc dust and test the issuing vapors with a pine splinter dipped in hydrochloric acid. The formation of a red-to-violet color indicates an amino acid. This test is given by ammonium salts of many organic acids, and by nitrogenous derivatives of the sugars.

Test 5d. Primary aromatic amines. To an ice-cold solution of the base in 1.0 *N* hydrochloric acid add a saturated sodium nitrite solution, drop by drop, until it gives an immediate reaction to starch iodide paper. Add a few drops to an alkaline solution of α-naphthol; an intensely colored precipitate indicates an aromatic amine. Even if the diazotized solution is colored, the test can still be performed by comparing the color produced when small portions of the solution are added respectively to a cold alkaline solution of α-naphthol and to a cold solution of alkali alone. A marked difference in the colors of the two resulting mixtures indicates the presence of a primary aromatic amine in the unknown. If a substance which is not a base gives this test, it contains an amine group in a benzene ring, but also some other group of an acidic nature, such as COOH or SO_3H.

A strongly basic substance (that is, one distinctly alkaline to phenolphthalein) which gives Test 5a but not 5b or 5d is a primary aliphatic amine. A neutral substance responding to Test 5a but not to Test 5b, 5c, or 5d is a primary amide (see Test 7) or a salt of a primary amine (see Test 1).

There are many other reactions of the $—NH_2$ group besides that of diazotization. Most of them are common to ammonia and secondary amines as well.

The addition of hydrogen ion to an amine leads to salt formation. This has been discussed elsewhere (p. 193).

$$RNH_2 + H^+ \longrightarrow RNH_3^+.$$

It is not peculiar to primary amines, but also occurs with secondary and tertiary amines.

The ionization of hydrogen from nitrogen takes place to an appreciable extent in relatively few instances. It is evidenced by the reaction of aqueous alkali with the diamides, sulphonamides, nitroamines, and cyanamides.

The alkylation of amines by alkyl iodides and silver oxide, by dimethyl sulphate, and by diazomethane occurs with both primary and secondary amines.

$$R—NH_2 + RI + OH^- \longrightarrow R_2NH + I^- + H_2O.$$

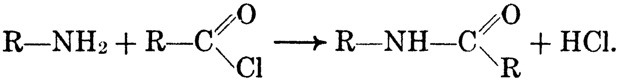
$$R—NH_2 + (CH_3)_2SO_4 \longrightarrow R—NH—CH_3 + CH_3HSO_4.$$

$$R—NH_2 + CH_2N_2 \longrightarrow R—NH—CH_3 + N_2.$$

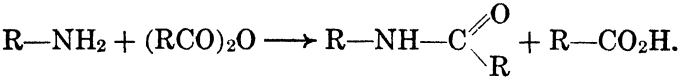
Amines are readily acylated. Benzenesulphonyl chloride reacts with primary amines to give acidic amides. Secondary amines form neutral amides (Hinsberg reaction). This reaction affords a means of separating the components of a mixture containing primary, secondary, and tertiary amines. It is useful in distinguishing primary from secondary amines. Carboxylic acid chlorides, acid anhydrides, and esters form amides with primary and secondary amines:

$$\mathrm{R{-}NH_2 + C_6H_5SO_2Cl \xrightarrow{OH^-} \underset{\text{Soluble in alkali}}{R{-}NH{-}SO_2C_6H_5} + HCl.}$$

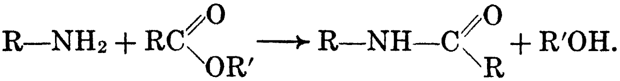
$$\mathrm{R_2NH + C_6H_5SO_2Cl \xrightarrow{OH^-} \underset{\text{Insoluble in alkali}}{R_2N{-}SO_2C_6H_5} + HCl.}$$



$$\mathrm{R{-}NH_2 + R{-}C}\begin{smallmatrix}/\!\!/\mathrm{O}\\ \diagdown\mathrm{Cl}\end{smallmatrix} \longrightarrow \mathrm{R{-}NH{-}C}\begin{smallmatrix}/\!\!/\mathrm{O}\\ \diagdown\mathrm{R}\end{smallmatrix} + \mathrm{HCl.}$$



$$\mathrm{R{-}NH_2 + (RCO)_2O} \longrightarrow \mathrm{R{-}NH{-}C}\begin{smallmatrix}/\!\!/\mathrm{O}\\ \diagdown\mathrm{R}\end{smallmatrix} + \mathrm{R{-}CO_2H.}$$



$$\mathrm{R{-}NH_2 + RC}\begin{smallmatrix}/\!\!/\mathrm{O}\\ \diagdown\mathrm{OR'}\end{smallmatrix} \longrightarrow \mathrm{R{-}NH{-}C}\begin{smallmatrix}/\!\!/\mathrm{O}\\ \diagdown\mathrm{R}\end{smallmatrix} + \mathrm{R'OH.}$$

Carbonyl derivatives such as ketones and aldehydes form substituted imides with hydroxylamine, hydrazines, and primary aromatic amines. The corresponding derivatives of ammonia and of the primary aliphatic amines are unstable or polymerized. The certification of the formation of an imine is usually more difficult than other methods of demonstrating the presence of an $-NH_2$ group.

$$\mathrm{R'{-}NH_2 + R{-}CHO \longrightarrow R{-}CH{=}N{-}R' + H_2O.}$$

The Grignard reagent reacts with primary and secondary amines as it does with acids, liberating the hydrocarbon. The hydroxyl groups of alcohols, acids, phenols, water, etc. also react in the same way.

$$\mathrm{RNH_2 + CH_3MgI \longrightarrow RNHMgI + CH_4.}$$

Primary and secondary amines form bromamines of the types $RNHBr$ and R_2NBr respectively in neutral or alkaline solutions upon the addition of bromine. They are unstable in acid solution, giving hypobromous acid, and as a rule they are difficult to isolate. The bromamines derived from aromatic amines readily undergo a rearrangement which results in the formation of *ortho*-bromo or *para*-bromo derivatives.

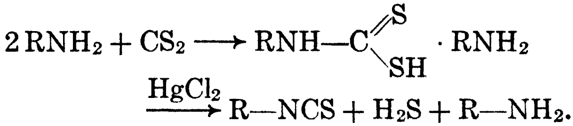
$$RNH_2 + Br_2 \xrightarrow{OH^-} RNHBr + HBr.$$

$$C_6H_5NHBr \xrightarrow{H^+} BrC_6H_4NH_2.$$

The carbylamine reaction is a special case of alkylation. Chloroform and a primary amine yield, in the presence of alcoholic potassium hydroxide, an isocyanide or carbylamine of characteristic odor. This reaction is given by primary, but not by secondary, amines.

$$RNH_2 + CHCl_3 \xrightarrow{OH^-} RNC + 3\,HCl.$$

The mustard oil reaction is a special case of acylation. Aliphatic primary amines and carbon disulphide yield salts of substituted dithiocarbamic acids, which in turn, on treatment with mercuric chloride solution, are converted into isothiocyanates of characteristic odor. Aromatic primary amines yield substituted thioureas.



$$2\,RNH_2 + CS_2 \longrightarrow RNH{-}C\begin{matrix}{\nearrow}S \\ {\searrow}SH\end{matrix} \cdot RNH_2 \xrightarrow{HgCl_2} R{-}NCS + H_2S + R{-}NH_2.$$

$$2\,C_6H_5NH_2 + CS_2 \longrightarrow (C_6H_5NH)_2CS + H_2S.$$

TEST 6. SECONDARY AMINES, TERTIARY AROMATIC AMINES, AMINOPHENOLS, AROMATIC DIAMINES, SECONDARY HYDRAZINES, DIARYLAMINES, PYRROL AND CARBAZOL DERIVATIVES

Evidence of the presence of any of these classes of substances will be found under Test 6a or 6b. Specific tests for certain classes are given in Tests 6c and 6d.

Test 6a is a color test for water-soluble aliphatic amines, known as Simon's test. It is based upon a color produced from a mixture of acetaldehyde, a secondary amine, and sodium nitroprusside, $Na_2FeNO(CN)_5$. Primary amines give a color different from that produced by secondary amines. The exact nature of the colored compound is not known. The test is not of very wide application, and in the event of failure Test 6b should be tried.

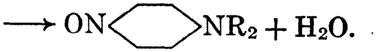
Test 6b depends upon the formation and isolation of a secondary nitrosoamine (see discussion of the reaction under Test 5):

$$R_2NH_2^+ + NO_2^- \rightleftarrows R_2N{-}NO + H_2O.$$

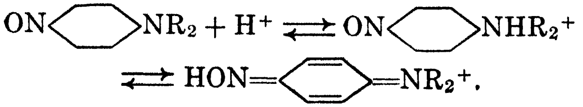
The isolation of a new compound is insufficient evidence of the formation of a nitrosoamine. The product (or an ether solution containing it) is therefore subjected to the specific test for nitrosoamines outlined in Test 3c. It must be remembered that nitrosophenol gives the color upon which that test is based (indophenol), and that even traces of nitrite ion produce the color. Care is taken, therefore, in separating and washing the ethereal extract presumably containing the nitrosoamine, to remove all traces of nitrous acid. Extraction with ether from an alkaline solution is necessary for two reasons: (1) the nitroso derivatives of tertiary aromatic amines are weak bases and therefore somewhat soluble in aqueous acid; (2) oxides of nitrogen are soluble in ether, but nitrite and nitrate ions are not.

Evidence of the presence of tertiary aromatic amines of the type $C_6H_5NR_2$ can be obtained from Test 6b. These compounds react with nitrous acid in a manner similar to the reaction with aromatic diazohydroxides:

$$C_6H_5NHR_2^+ + NO_2^- \longrightarrow \left[C_6H_5N(NO)R_2^+ + OH^-\right]$$



The *carbon*-nitroso compounds are blue or green in solution, although the salts of the *para*-nitrosoaryldialkylamines are yellow. This may be explained on the basis of the nitroso-oxime equilibrium:



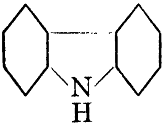
Acid therefore favors the existence of a yellow water-soluble oxime, and alkali favors a blue or green ether-soluble nitroso compound. Hence a yellow solution on diazotization with a green ethereal layer from alkaline solution indicates the presence of a tertiary aromatic amine.

If diazotization produces a substance which is neither an *N*-nitroso nor a *C*-nitroso compound, and if that product has the appearance of an azo compound derived from coupling a diazohydroxide with an amine or phenol, then the substance being tested is one of the aminophenols or diamines that did not give nitrogen gas in Test 5a, owing to excessively rapid coupling with itself. Aminophenols, like other phenols, give characteristic colors when treated with ferric ion.

Secondary hydrazines are readily oxidized by Fehling's solution to azo compounds:

$$\mathrm{RNH{-}NHR} + 2\,\mathrm{Cu^{++}} + 4\,\mathrm{OH^-} \longrightarrow \mathrm{RN{=}NR} + \mathrm{Cu_2O} + 3\,\mathrm{H_2O}.$$

Diarylamines, $(C_6H_5)_2NH$, and derivatives of carbazol,



are readily oxidized and condensed to colored compounds of the indophenol type.

The color produced by the vapor of pyrrol derivatives when reacting with an acidified pine splinter is due to the fact that the phenols present in the wood condense with the pyrrol.

Test 6a. Water-soluble secondary amines. Heat a spiral of copper wire to red heat and dip it into 5 cc. of 50 per cent ethyl alcohol in water. Repeat a few times until the odor of acetaldehyde is evident. Cool the solution and add 0.1 g. of the unknown and two drops of a 1 per cent solution of sodium nitroprusside. Allow the mixture to stand a few minutes. A blue color indicates an aliphatic secondary amine. Perform similar tests on known primary and secondary amines for purposes of comparison.

Test 6b. Secondary amines, tertiary aromatic amines, aromatic diamines, and aminophenols. If Test 6a is negative, dissolve 1 g. of the unknown in 20 cc. of 1.0 *N* hydrochloric acid, using an alcoholic solution of the acid if necessary to effect solution. Cool the solution in ice and slowly add to it 1 g. of sodium nitrite dissolved in water. If the sodium nitrite appears at any time to be greatly in excess, as evidenced by the odor of oxides of nitrogen, do not add all the nitrite solution. If alcohol has been used as a solvent, dilute the mixture with an equal volume of water. Note the presence and character of any color or precipitate in the mixture. Add sufficient ether to form an ether layer of at least 20 cc. in volume, and then make the mixture slightly alkaline by the addition of 6 *N* sodium hydroxide. A small piece of litmus paper suspended in the water layer will serve to indicate when the solution is alkaline. Remove the water layer by means of a separatory funnel, wash the ether layer carefully with dilute sodium carbonate solution, and dry it with anhydrous sodium sulphate. Observe carefully any changes in the color that have occurred and the disappearance of any precipitate from the water layer by solution in the ether.*

A yellow solution in acid, giving a green ethereal extract on the addition of sodium hydroxide, indicates that the original substance is a dialkylarylamine.

Evaporate off the ether from the ether layer and test the residue for a nitrosoamine (Test 3c). The production of a nitrosoamine indicates that the unknown contains the >NH group. If a new substance is obtained which is neither a nitroso derivative of a dialkylarylamine nor a nitroso derivative of a secondary amine, the unknown is probably an aminophenol or an aromatic diamine. The phenol group may be detected by testing the original substance with ferric chloride and obtaining a red or violet color. Do not attempt to determine melting points of substances obtained by the action of nitrous acid until it has been found that they are not explosive. This can be done by heating a small quantity on a spatula until it melts.

Test 6c. Secondary hydrazines. If the substance contains the secondary amine group as indicated in tests outlined above and is a base, treat it with Fehling's solution. A red precipitate formed at room temperature indicates a secondary hydrazine.

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* If the product of the reaction with nitrous acid is insoluble in water and in ether, it may be filtered off, washed thoroughly with sodium carbonate solution, and subjected to the confirmatory test for nitrosoamines (Test 3c).

Test 6d. Diarylamines and carbazol derivatives. If the substance is practically nonbasic, dissolve it in concentrated sulphuric acid and add a trace of nitric acid. A blue or a green color indicates the presence of a diarylamine or of a carbazol derivative.

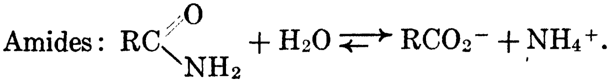
Test 6e. Pyrrol derivatives. Allow the vapors of the substance to come in contact with a pine splinter moistened with concentrated hydrochloric acid; a red or violet color indicates a pyrrol derivative.

Should a substance be basic, but unaffected by nitrous acid in Tests 5 and 6, it is a tertiary aliphatic amine, a pyridine, or quinoline derivative, or a quaternary ammonium hydroxide. Triarylamines are not basic; they are rare and inert compounds.

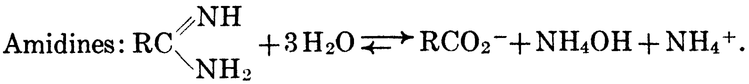
Other reactions of secondary amines are discussed under primary amines (Test 5).

TEST 7. AMIDES, AMIDINES, ISONITRILES, NITRILES, ESTERS

The types of substances detected under Test 7 are, as a rule, practically neutral substances, mostly solids or high-boiling liquids. Their most characteristic reaction is hydrolysis to form ammonium or amine salts of carboxylic acids or, in the case of esters, to form alcohols and acids. The reactions may be written:



$$\text{Amides: } RC\begin{smallmatrix}\nearrow O\\ \searrow NH_2\end{smallmatrix} + H_2O \rightleftarrows RCO_2^- + NH_4^+.$$



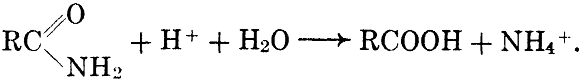
$$\text{Amidines: } RC\begin{smallmatrix}\nearrow NH\\ \searrow NH_2\end{smallmatrix} + 3\,H_2O \rightleftarrows RCO_2^- + NH_4OH + NH_4^+.$$

$$\text{Nitriles: } RC{\equiv}N + 2\,H_2O \rightleftarrows RCO_2^- + NH_4^+.$$

$$\text{Isonitriles: } RN{=}C + 2\,H_2O \rightleftarrows HCO_2^- + RNH_3^+.$$

$$\text{Esters: } RCO_2R' + H_2O \rightleftarrows RCO_2H + R'OH.$$

The equilibrium in each of the above cases in dilute aqueous solution is greatly in favor of the salt, that is, the hydrolyzed product. The hydrolysis is, however, in most cases very slow, and is catalyzed by both H^+ ion and OH^- ions. Acidic catalysis is more efficient as a rule, so that in Test 7 a weighed sample is first heated in a known amount of dilute acid. The solution, after completion of the reaction, contains the organic acid and ammonium (or amine) ion:



$$RC\begin{matrix}{\diagup O}\\{\diagdown NH_2}\end{matrix} + H^+ + H_2O \longrightarrow RCOOH + NH_4^+.$$

Since either the original amide or the free acid may distill with steam, the reaction is carried out either under a reflux condenser or in a bomb tube. With carefully controlled heating the Kjeldahl flask and trap offer in most cases sufficient refluxing. When the reaction is completed, as determined by complete solution or by successive trials involving more and more time, a known excess of alkali is added and about 100 cc. of water is distilled over into a known amount of acid. The alkali changes the substances present according to the equations

$$RCO_2H + OH^- \longrightarrow RCO_2^- + H_2O.$$
$$NH_4^+ + OH^- \longrightarrow NH_3 + H_2O.$$

The ammonia or amine, if sufficiently volatile, distills over with the steam. Many aromatic amines will not distill completely and may be observed to separate as solids or oils in the condenser. After the distillation the distillate is back-titrated with standard alkali, with methyl orange as indicator, and the residue is titrated with standard acid, with phenolphthalein as indicator. The amount of acid and base formed by the hydrolysis may be calculated from the result. A sample calculation is here given:

1. Acid added to hydrolyze	0.050 equiv.
2. Alkali added to liberate amines	0.100 equiv.
3. Acid in receiver	0.030 equiv.
4. Alkali to back-titrate receiver	0.010 equiv.
5. Acid to back-titrate residue	0.030 equiv.

Calculation: Equivalents of base formed: 0.020 equiv.
Equivalents of acid formed: 0.020 equiv.

If the base is aromatic and does not steam-distill completely, the amount of base apparently formed will be low; but that of the acid detected will be correct, since the aromatic bases do not affect phenolphthalein indicator. The ratio in equivalents of acid to base formed is significant in determining the nature of the compound. The equivalent weight, as calculated from the weight of sample and the number of equivalents of base or acid formed by hydrolysis, is used for the same purpose. The neutral residue may be tested for volatile acids (except carbonic acid) and insoluble acids, etc., as in Test 3b, Division I. The amine salt in the distillate may be considered as a new unknown and identified. If acid is found and little or no base, the substance may be an ester or an amide of a nondistillable base. In the latter case the amine may be seen to precipitate from an alkaline solution or may be extracted with ether.

Test 7. Boil a weighed quantity, about 2 g. of the substance, with 50 cc. of 1.0 *N* acid in a flask fitted with a reflux condenser. The apparatus used for the distillation of ammonia in the Kjeldahl method may be used if care is taken to prevent any distillation during the hydrolysis. The hydrolysis should be continued for about two hours, unless it is apparent that the reaction has been completed before that time. Cool the reaction flask and add from a burette or pipette a measured quantity (about 100 cc.) of 1.0 *N* alkali which contains no carbonate ion. Distill 100 cc. of water from the mixture through a Kjeldahl trap into a receiver containing 40 cc. of 1.0 *N* acid. Titrate the excess acid in the receiver with methyl orange as indicator and examine the contents for ammonia and organic bases (see Test 1).

Weak organic bases cannot be titrated satisfactorily with methyl orange as indicator, but they are in general very slightly soluble in water and may be extracted from a weakly alkaline solution with ether. To obtain the pure salt of a strong base distill again with steam from an alkaline solution into dilute hydrochloric acid, evaporate to dryness on a water bath, and separate the salts of ammonia and amines as in Test 1. A few chlorides, such as dimethylenediamine hydrochloride, are not very soluble in alcohol but are easily distinguished from ammonium chloride.

Back-titrate the residue from the first distillation with 1.0 *N* acid, using phenolphthalein as indicator. Isolate any water-insoluble liquid or solid substance present by filtration or by extraction with ether. It may be the unchanged substance or a neutral or basic product of hydrolysis which does not readily distill with steam. It should be examined as a new unknown and identified. Examine the clarified aqueous solution as in Test 3b, Division I, to identify any organic acid whose presence has been indicated by the previous titration.

Should the titrations indicate the formation by hydrolysis of an amount of acid equivalent to 1 cc. or more of the standard solution, the substance belongs to one of the classes of compounds included under this test. Proper correction should be made if the original substance is a titratable acid (Test 2).

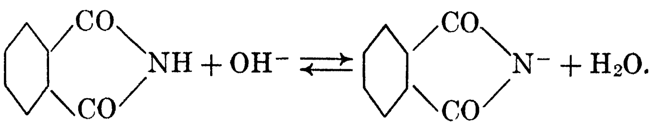
The formation of both an acid and a base indicates an amide, an amidine, a nitrile, an isonitrile, or a salt. The formation of an acid only indicates the ester of a nitrogen-containing acid or of a polypeptide. The formation of a base only shows an amino-keto-condensation product.

Calculate an equivalent weight for the substance on the basis of the acid produced by hydrolysis. The result cannot be considered accurate until it has been reproduced with a second sample, using a longer time for hydrolysis. The equivalent weight may also be calculated from the amount of base formed, although this may be less reliable due to incomplete distillation or to incomplete titration of the base.

The classes of compounds included in Test 7 give many reactions other than hydrolysis. Some of these may be noted. Only in rare instances are the reactions useful for the certification of the compound as an amide or a nitrile, but they are extremely valuable for synthetic purposes.

The amides are weak acids. This is demonstrated by the solubility in alkali of certain water-insoluble amides.

$$C_6H_5SO_2NHR + OH^- \rightleftarrows (C_6H_5SO_2NR)^- + H_2O.$$

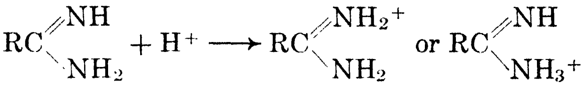


The first example is used in the Hinsberg separation of amines; the second is used in Gabriel's method of preparing primary amines. Refer to the table of acidic substances given under Test 2 for some amides that may be considered as definitely acidic substances.

The simple amides are extremely weak acids. Diamides or imides of the type $(RCO)_2NH$, such as phthalimide, are much stronger but still very weak acids. The salts of these acids are highly hydrolyzed in water. Metallic derivatives of the amides are usually prepared, therefore, in a less acidic solvent than water, and by using the salt of a still weaker acid for the metathesis, such as an alcoholic solution of sodium ethylate:

$$RCO_2NH + ROK \longrightarrow RCO_2NK + ROH.$$

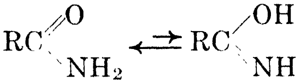
The amidines are weak bases. Other classes included here are practically neutral substances, or slightly acidic. The addition of hydrogen ion to amidines takes place as follows:



$$RC\begin{cases}=NH\\ -NH_2\end{cases} + H^+ \longrightarrow RC\begin{cases}=NH_2^+\\ -NH_2\end{cases} \text{ or } RC\begin{cases}=NH\\ -NH_3^+\end{cases}$$

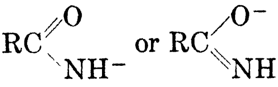
The structure of the ion is unknown.

The amides are thought to exhibit tautomerism. The reaction is



$$RC\begin{cases}=O\\ -NH_2\end{cases} \rightleftarrows RC\begin{cases}-OH\\ =NH\end{cases}$$

Derivatives of both types are known, the substituted amide, $RC(=O)-NHR$, and the imido ester, $RC(-OR)=NH$. The facts indicate that the above equilibrium favors the amide form rather than the imido acid. The anion of the salt of an amide may be represented by two structures,



$$RC\begin{cases}=O\\ -NH^-\end{cases} \text{ or } RC\begin{cases}-O^-\\ =NH\end{cases}$$

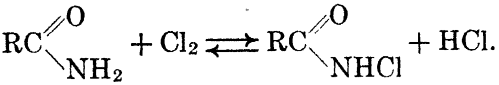
Probably both forms exist to some extent, equilibrium being established in all such cases.

Nitriles may also tautomerize:

$$RCH_2CN \rightleftarrows RCH{=}CNH.$$

The equilibrium favors the nitrile rather than the imine.

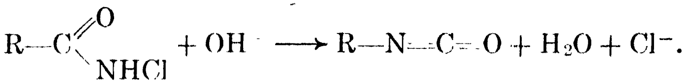
The first reaction of chlorine with an amide or with a nitrile is substitution at the point of the most reactive hydrogen:



$$RC\begin{cases}=O\\ -NH_2\end{cases} + Cl_2 \rightleftarrows RC\begin{cases}=O\\ -NHCl\end{cases} + HCl.$$

$$RCH_2CN + Cl_2 \longrightarrow RCHCl{-}CN + HCl.$$

In alkaline solution the former undergoes the Hofmann rearrangement; the latter product simply hydrolyzes.



$$\mathrm{R{-}C}\left\langle\begin{array}{l}\mathrm{O}\\ \mathrm{NHCl}\end{array}\right. + \mathrm{OH^-} \longrightarrow \mathrm{R{-}N{=}C{=}O} + \mathrm{H_2O} + \mathrm{Cl^-}.$$

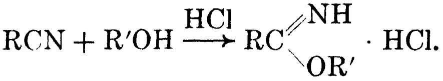
$$\mathrm{R{-}CHCl{-}CN} + \mathrm{OH^-} \longrightarrow \mathrm{R{-}CH(OH)CN} + \mathrm{Cl^-}.$$

An isocyanate and a cyanhydrin may each react further:

$$\mathrm{RNCO} + 2\,\mathrm{H_2O} \longrightarrow \mathrm{RNH_2} + \mathrm{H_2CO_3}.$$
$$\mathrm{RCH(OH)CN} + 2\,\mathrm{H_2O} \longrightarrow \mathrm{RCH(OH)COONH_4}.$$

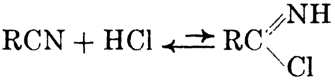
The final result of the treatment with chlorine will depend upon the conditions of the experiment.

A clue as to the nature of the hydrolytic process applied to imines is afforded by the reaction of nitriles with alcohol in the presence of hydrogen chloride:



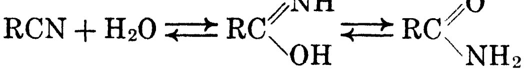
$$\mathrm{RCN} + \mathrm{R'OH} \xrightarrow{\mathrm{HCl}} \mathrm{RC}\left\langle\begin{array}{l}\mathrm{NH}\\ \mathrm{OR'}\end{array}\right. \cdot \mathrm{HCl}.$$

The reaction probably involves the equilibrium



$$\mathrm{RCN} + \mathrm{HCl} \rightleftarrows \mathrm{RC}\left\langle\begin{array}{l}\mathrm{NH}\\ \mathrm{Cl}\end{array}\right.$$

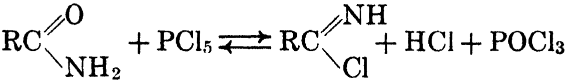
The compound RCCl:NH is the acid chloride of the imido acid, and as such would react with alcohol to form the ester. Hydrolysis, if it proceeded along the same line, would be represented as follows:



$$\mathrm{RCN} + \mathrm{H_2O} \rightleftarrows \mathrm{RC}\left\langle\begin{array}{l}\mathrm{NH}\\ \mathrm{OH}\end{array}\right. \rightleftarrows \mathrm{RC}\left\langle\begin{array}{l}\mathrm{O}\\ \mathrm{NH_2}\end{array}\right.$$

Nitriles may be hydrolyzed to acid amides as well as to acids, and primary amides may be dehydrated to nitriles.

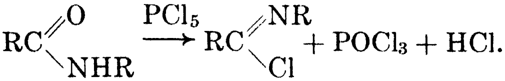
Acid amides, on treatment with phosphorus pentachloride, form the acid chlorides of the imido acids. The latter decompose, yielding nitriles.



$$\mathrm{RC}\left\langle\begin{array}{l}\mathrm{O}\\ \mathrm{NH_2}\end{array}\right. + \mathrm{PCl_5} \rightleftarrows \mathrm{RC}\left\langle\begin{array}{l}\mathrm{NH}\\ \mathrm{Cl}\end{array}\right. + \mathrm{HCl} + \mathrm{POCl_3}$$

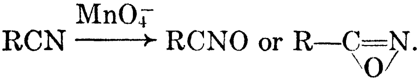
$$\mathrm{RCCl{:}NH} \rightleftarrows \mathrm{RCN} + \mathrm{HCl}.$$

With substituted amides the formation of the nitrile is blocked and the chloro derivative may be isolated.



$$\mathrm{RC}{\begin{smallmatrix}\diagup\!\!\diagup \mathrm{O}\\ \diagdown \mathrm{NHR}\end{smallmatrix}} \xrightarrow{\mathrm{PCl_5}} \mathrm{RC}{\begin{smallmatrix}\diagup\!\!\diagup \mathrm{NR}\\ \diagdown \mathrm{Cl}\end{smallmatrix}} + \mathrm{POCl_3} + \mathrm{HCl}.$$

The oxidation of cyanides and isocyanides leads to cyanates and isocyanates respectively:



$$\mathrm{RCN} \xrightarrow{\mathrm{MnO_4^-}} \mathrm{RCNO} \text{ or } \mathrm{R{-}C{=}N}.$$

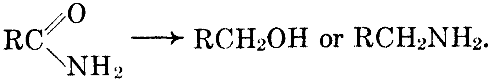
$$\mathrm{RNC} \xrightarrow{\mathrm{MnO_4^-}} \mathrm{RNCO}.$$

Reduction results in the formation of amines:

$$\mathrm{RCN} \xrightarrow[\mathrm{(Pt)}]{\mathrm{H_2}} \mathrm{RCH_2NH_2},$$

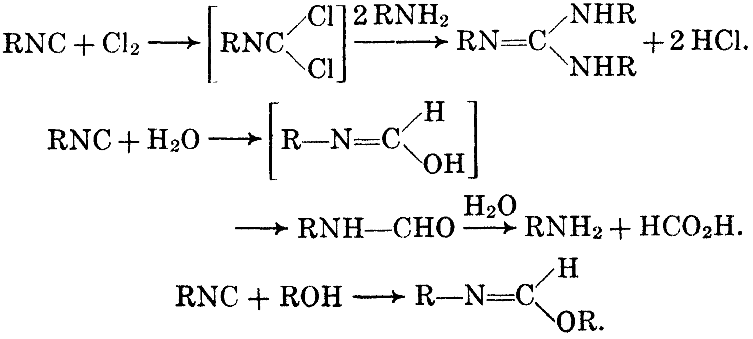
$$\mathrm{RNC} \xrightarrow[\mathrm{(Pt)}]{\mathrm{H_2}} \mathrm{RNHCH_3}.$$

It is more difficult to reduce amides:



$$\mathrm{RC}{\begin{smallmatrix}\diagup\!\!\diagup \mathrm{O}\\ \diagdown \mathrm{NH_2}\end{smallmatrix}} \longrightarrow \mathrm{RCH_2OH} \text{ or } \mathrm{RCH_2NH_2}.$$

The reactions of isonitriles indicate the presence of bivalent carbon:



$$\mathrm{RNC} + \mathrm{Cl_2} \longrightarrow \left[\mathrm{RNC}{\begin{smallmatrix}\diagup \mathrm{Cl}\\ \diagdown \mathrm{Cl}\end{smallmatrix}}\right] \xrightarrow{2\,\mathrm{RNH_2}} \mathrm{RN{=}C}{\begin{smallmatrix}\diagup \mathrm{NHR}\\ \diagdown \mathrm{NHR}\end{smallmatrix}} + 2\,\mathrm{HCl}.$$

$$\mathrm{RNC} + \mathrm{H_2O} \longrightarrow \left[\mathrm{R{-}N{=}C}{\begin{smallmatrix}\diagup \mathrm{H}\\ \diagdown \mathrm{OH}\end{smallmatrix}}\right]$$

$$\longrightarrow \mathrm{RNH{-}CHO} \xrightarrow{\mathrm{H_2O}} \mathrm{RNH_2} + \mathrm{HCO_2H}.$$

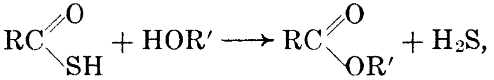
$$\mathrm{RNC} + \mathrm{ROH} \longrightarrow \mathrm{R{-}N{=}C}{\begin{smallmatrix}\diagup \mathrm{H}\\ \diagdown \mathrm{OR}\end{smallmatrix}}.$$

DIVISION III. COMPOUNDS CONTAINING SULPHUR

TESTS 1, 2, AND 3. THE THIO COMPOUNDS

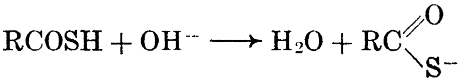
The prefix *thio* indicates that the compound is similar in structure to the substance designated by the same name without the prefix except that it has a divalent sulphur atom in the place of an oxygen atom.

Many of the chemical properties of the thio compounds are similar to those of the corresponding oxygen compounds, and consequently they may give the tests characteristic of the classes of substances described under Division I. Thus the thio acids, which are characterized by the structure $R-\overset{O}{\overset{/\!\!/}{C}}-SH$, like the carboxylic acids, may be esterified with alcohols,



$$RC\begin{array}{l}{/\!\!/}O\\ \backslash SH\end{array} + HOR' \longrightarrow RC\begin{array}{l}{/\!\!/}O\\ \backslash OR'\end{array} + H_2S,$$

and titrated with alkalies if phenolphthalein is used as the indicator,



$$RCOSH + OH^- \longrightarrow H_2O + RC\begin{array}{l}{/\!\!/}O\\ \backslash S^-\end{array}$$

Consequently, if a substance contains sulphur, the tests of Division I may fail to distinguish between the oxygen-containing group and the sulphur-containing group.

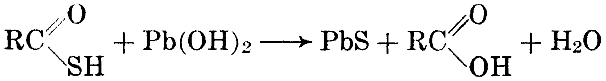
The divalent sulphur compounds differ from the corresponding oxygen compounds, however, in that they are readily oxidized. In this way disulphides, sulphoxides, sulphinic acids, sulphones, and sulphonic acids may be formed:

$$R{-}SH \xrightarrow{\text{Oxidation}} R{-}S{-}S{-}R$$
$$R{-}SH \xrightarrow{\text{Oxidation}} R{-}SO_2H \xrightarrow{\text{Oxidation}} RSO_3H$$
$$R_2S \xrightarrow{\text{Oxidation}} R_2SO \xrightarrow{\text{Oxidation}} R_2SO_2.$$

This property is not suitable as the basis of a test, owing to the number of possible types of substances which may result, and to the fact that oxidation may affect other portions of the molecule as well.

Divalent sulphur compounds also differ from oxygen compounds in that they are malodorous. This is not sufficiently characteristic to serve as a test, though it is often a valuable indication that sulphur is present in the divalent state.

The divalent sulphur compounds are characterized by the ease with which they react with compounds of the heavy metals, either to form metallic sulphides or to form metallic thio organic compounds. This property is the basis of Tests 1 and 2. With mercuric oxide many of the divalent sulphur compounds form mercuric sulphide, while the thio alcohols (called mercaptans) and the thiophenols form stable salts:



$$RC\begin{matrix}\nearrow O\\ \searrow SH\end{matrix} + Pb(OH)_2 \longrightarrow PbS + RC\begin{matrix}\nearrow O\\ \searrow OH\end{matrix} + H_2O$$

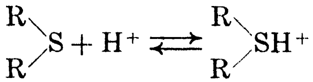
$$2\,RSH + HgO \longrightarrow H_2O + (RS)_2Hg.$$

The formation of a solid salt of mercury from mercuric oxide depends upon two factors: first, the strength of the acid; second, the insolubility of the salt. Any distinctly acidic substance will react with mercuric oxide, and therefore a reaction of salt formation cannot be considered distinctive unless the compound is a very weak acid. Of the weak acids, such as alcohols, phenols, and mercaptans, it happens that mercury salts of the last only are rapidly formed from mercuric oxide and are insoluble in alcohol. Consequently, if the substance is too weak an acid to be titrated when phenolphthalein is the indicator (see Test 4), but forms a salt with mercuric oxide (see Test 2), the substance is a mercaptan.

In Test 1 the substance is treated with an alcoholic solution of sodium plumbite, $NaHPbO_2$, which decomposes most of the thio compounds, forming lead sulphide.

The thio compounds also form double salts with many compounds of mercury, silver, and lead, and with other metals which form very difficultly soluble sulphides. Tests involving these reactions have not been included in this outline.

Divalent sulphur also differs from oxygen in its power to form stable *onium* salts, but this property is not sufficiently great to endow compounds containing divalent sulphur with marked basic properties, for the equilibria of the type



$$R_2S + H^+ \rightleftharpoons R_2SH^+$$

are too far displaced toward the system, sulphide and hydrogen ion, to permit the titration of a sulphide with an acid. If, however, no hydrogen is attached to the sulphur atom of an ion of the above type, the salts of such ions may be obtained, and the corresponding hydroxides, which are strong bases, may be prepared by double decomposition. Thus, when a thioether is treated with an alkyl iodide, an alkylated sulphonium iodide is obtained, which with silver oxide and water gives a solution of an alkylated sulphonium hydroxide, whose presence may be shown by a test for hydroxide ion. These changes may be represented by the following equations:

$$R_2S + R'I \longrightarrow R_2SR'^+ + I^-.$$

$$2\,R_2SR'^+ + 2\,I^- + Ag_2O + H_2O \longrightarrow 2\,R_2SR'^+ + 2\,OH^- + 2\,AgI.$$

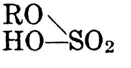
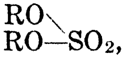
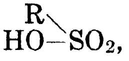
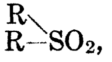
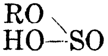
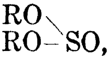
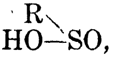
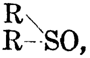
This is the basis of Test 3 for thioethers. The test is not valid if nitrogen is present, for the property of forming *onium* salts is much more characteristic of trivalent nitrogen than of divalent sulphur. The thioaldehydes and thioketones, which are generally polymerized, also form double compounds with alkyl iodides.

Test 1. Divalent sulphur. To a 1 *M* solution of lead acetate add enough 12 *N* sodium hydroxide to dissolve all the lead hydroxide which was formed when the first few drops of sodium hydroxide were added. Dilute the resulting solution with five times its volume of alcohol. Add about 0.1 g. of the unknown to 5 cc. of this solution, and heat the mixture for a few minutes. A dark precipitate (PbS) indicates the presence of divalent sulphur in the unknown.

Test 2. Mercaptans. Add a few tenths of a gram of mercuric oxide to 5 cc. of a 10 per cent solution of the unknown in alcohol, and shake the mixture for five minutes. If the mercuric oxide becomes dark in color, mercuric sulphide has been formed and the unknown is a thio compound, but the absence of this phenomenon does not show that the substance is not a thio compound. Any colorless or slightly colored solid which is formed is a mercuric salt of the unknown; and if the unknown is not acidic in a titration with phenolphthalein as indicator, the formation of the mercuric salt shows that the unknown is a mercaptan.

Test 3. Thioethers. Warm a mixture of approximately 1 g. of the unknown and 2 cc. of ethyl iodide in a test tube for five minutes. Transfer the resulting mixture to a small beaker and evaporate off any volatile material by gently warming it. Allow the mixture to cool for a few minutes. Shake 0.5 g. of the residue with the same amount of freshly precipitated and well-washed silver oxide, and 10 cc. of water. Filter the resulting mixture and wash the precipitate with water, collecting the filtrate and washings. Add a drop of phenolphthalein solution to the combined filtrate and washings and titrate with 0.1 *N* hydrochloric acid. If more than 1 cc. of the hydrochloric acid is necessary to neutralize the solution, ascertain whether this result could be due to alkali adsorbed on the silver oxide, by repeating the process on the same amount of silver oxide taken from the same preparation as that which was used in the previous experiment. If the amount of acid required in the experiment is as much as 1 cc. in excess of that used in the blank, the test shows that a sulphonium iodide was formed in the reaction between the ethyl iodide and the unknown, and consequently that the latter is a thioether or possibly a polymerized thioaldehyde or thioketone. This test cannot be applied if the unknown contains nitrogen, for a positive result might be due to the formation of a substituted ammonium iodide and not to that of a sulphonium salt.

TESTS 4, 5, 6, AND 7. COMPOUNDS CONTAINING SULPHUR IN ITS HIGHER VALENCES

The chief classes of organic substances containing oxidized sulphur may be considered as derivatives of sulphuric and sulphurous acids, hydrogen atoms or hydroxyl groups being replaced by organic radicals. In this way the mono-esters and di-esters of sulphuric acid,  $\genfrac{}{}{0pt}{}{RO\diagdown}{HO{-}}SO_2$ and  $\genfrac{}{}{0pt}{}{RO\diagdown}{RO{-}}SO_2$, the sulphonic acids,  $\genfrac{}{}{0pt}{}{R\diagdown}{HO{-}}SO_2$, and the sulphones,  $\genfrac{}{}{0pt}{}{R\diagdown}{R{-}}SO_2$, may be considered as derivatives of sulphuric acid; while the monoalkyl and di-alkyl sulphites,  $\overset{RO\diagdown}{HO{-}SO}$ and  $\overset{RO\diagdown}{RO{-}SO}$, the sulphinic acids,  $\overset{R\diagdown}{HO{-}SO}$, and the sulphoxides,  $\overset{R\diagdown}{R{-}SO}$, may be considered as derivatives of sulphurous acid.

Salts, esters, amides, and acid halides may be derived from any of the above classes of compounds which are acids, by such reactions as

$$RSO_2OH + PCl_5 \longrightarrow RSO_2Cl + HCl + POCl_3$$

and $$RSO_2Cl + 2\,NH_3 \longrightarrow NH_4Cl + RSO_2NH_2.$$

The dissociation constants of the acid derivatives of oxidized sulphur are generally greater than 1×10^{-3}; and if the sulphur is hexavalent, they are greater than 1×10^{-2}. On the other hand, those of the carboxylic and thiocarboxylic acids are, with very few exceptions, less than 10^{-3} if neither nitrogen nor halogen is present in the molecule. This is used as the basis of Test 4 to distinguish the two classes of acids. The result of the test is expressed not in terms of the dissociation constant of the acid but in terms of the fraction of a salt which reacts to form the undissociated acid at a standard concentration of hydrogen ion as determined by the color given with methyl violet (see page 251). This is done by preparing a solution of the salt containing a known number of equivalents. A strong acid is then added to this solution until the standard hydrogen ion concentration is reached. The excess of acid used, over that necessary to reach the standard hydrogen ion concentration in the same volume of water, gives the amount of undissociated acid. This amount in equivalents, divided by the number of equivalents of alkali used to form the salt, is the required fraction.

The dissociation constant of the acid titrated can be calculated from the numerical value of the standard hydrogen ion concentration and the fraction of the salt which is converted into the undissociated acid at that end point. If α represents this fraction, K_a the dissociation constant of the acid, and (H^+) the standard hydrogen ion concentration, then

$$K_a = \frac{1-\alpha}{\alpha} \times (H^+).$$

The numerical value of (H^+) in Test 4 is 5×10^{-3} *N*.* This formula is applicable only if the acid is monobasic. The procedure used in the test does not lead to a very accurate determination of the dissociation constant since the color comparison is not made with precision, and all effects of the salts present on the acid and the indicator are neglected.

The esters of sulphuric acid may be distinguished from the other classes of compounds by their rapid hydrolysis to produce sulphuric acid, for although sulphuric acid can be obtained from sulphonic acids by hydrolysis, the rate of the reaction is much slower. No appreciable quantities of sulphuric acid will be formed from a sulphonic acid under the conditions of Test 5. The sulphates of amines will respond to Test 5, but this will cause no confusion, as they can be shown to be salts by Tests 1a or 1b, Division II.

The esters of sulphuric acid differ markedly from those of carboxylic acids in the ease with which they react as alkylating agents. They are used to substitute an alkyl group for hydrogen attached to oxygen or nitrogen as in the reaction

$$ROH + (CH_3)_2SO_4 \longrightarrow ROCH_3 + CH_3SO_4H.$$

The sulphonic acids may be hydrolyzed under drastic conditions to yield either sulphuric or sulphurous acids:

$$\begin{gathered} R{-}CH_2{-}CH_2{-}SO_3Na + NaOH \\ \longrightarrow RCH{=}CH_2 + Na_2SO_3 + H_2O. \\ C_6H_5SO_3Na + NaOH \longrightarrow C_6H_5OH + Na_2SO_3. \\ C_6H_5SO_3H + H_2O \longrightarrow C_6H_6 + H_2SO_4. \end{gathered}$$

In general, an acid environment favors the formation of sulphuric acid, while hydrolysis with alkali produces alkaline sulphites and ethylenes or phenols. The hydrolysis in alkali is

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* The following is an example of such a calculation: A 1.0-gram sample of an acid required 9.0 cc. of 1.0 *N* alkali for titration, using phenolphthalein as the indicator. After this end point was reached methyl violet was added and the solution was titrated with 1.0 *N* acid to the blue end point. The amount of acid used was 3.0 cc. more than that required to obtain the same color of the indicator in an equal volume of water. The fraction of the salt transformed to the undissociated acid was 3 ÷ 9, or 0.33. Hence

$$K_a = \frac{.66}{.33} \times 5 \times 10^{-3}, \quad \text{or} \quad 1 \times 10^{-2}.$$

generally carried out by fusion with caustic potash, and this is the plan followed in Test 6.

The acid chlorides of the sulphonic acids are obtained by heating the sodium salts of the sulphonic acids with phosphorus pentachloride. From the acid chlorides the esters and amides are easily prepared by treatment with alcohols and with ammonia or amines respectively. These changes may be represented by the following equations:

$$RSO_3Na + PCl_5 \longrightarrow RSO_2Cl + NaCl + POCl_3.$$
$$RSO_2Cl + R'OH \longrightarrow HCl + RSO_3R'.$$
$$RSO_2Cl + 2\,R'NH_2 \longrightarrow R'NH_3^+ + Cl^- + RSO_2NHR'.$$

The sulphonamides are easily crystallizable and have definite melting points, so that they are often prepared as derivatives of sulphonic acids for the purpose of identifying the latter.

The sulphones are very inert substances, and no characteristic test for them has been included in this outline. They are not affected by the usual reducing agents used in organic chemistry, such as zinc and mineral acid; but by fusion with sulphur they are reduced to sulphoxides, a reaction analogous to the production of sulphur dioxide from sulphur and hot concentrated sulphuric acid. At high temperatures the sulphones undergo hydrolyses similar to those of the sulphonic acids.

The esters of sulphurous acid respond to the general hydrolysis test for esters, — Test 3b, Division I. They may be detected by the identification of sulphurous acid as a hydrolysis product. This characterization is not quite unique, as some sulphonic acids will yield sulphurous acid in this test.

The addition compounds of sodium bisulphite and ketones or aldehydes are generally thought to be the sodium salts of either mono-esters of sulphurous acid or of hydroxy sulphonic acids. On hydrolysis with alkali they give alkaline sulphites and ketones or aldehydes. This hydrolysis occurs quite easily in an aqueous solution of sodium carbonate and is made the basis of Test 7.

No tests have been included which are characteristic of the sulphinic acids, sulphoxides, and disulphides. They are all readily oxidized by permanganate ion, nitric acid, or other strong oxidizing agent. The sulphinic acids and disulphides yield sulphonic acids on oxidation, and the sulphoxides yield sulphones.

Test 4. **Acidic derivatives of sulphuric and sulphurous acids.** Grind the unknown to a fine powder and dissolve or suspend a weighed quantity (1 g.) in 10 cc. of water. Add a drop of phenolphthalein and titrate the solution with 1.0 *N* carbonate-free sodium hydroxide. Then add a drop or two of methyl violet solution and titrate it with 1.0 *N* hydrochloric acid until the color corresponds to that of a standard prepared by adding a drop of methyl violet solution and 0.1 cc. (2 drops) of 1.0 *N* hydrochloric acid to 20 cc. of water. Subtract 0.1 cc. for every 20 cc. of the final solution from the volume of hydrochloric acid used in the titration, and divide the result by the volume of 1.0 *N* sodium hydroxide used in the first titration. If this fraction is greater than $\frac{1}{2}$, the unknown is a carboxylic or thiocarboxylic acid. If the only elements present in the unknown are carbon, hydrogen, oxygen, and sulphur, then the only carboxylic or thiocarboxylic acids which would give a value less than $\frac{1}{2}$ are oxalic and thioxalic acid derivatives and sulphone-substituted acids. If the value is less than $\frac{1}{2}$, it indicates, except for the above acids, that the unknown is an acid derived from tetravalent or hexavalent sulphur. If the fraction is less than $\frac{1}{10}$, then the acid is an acid ester of sulphuric acid or a sulphonic acid. Dibasic acids will give values close to $\frac{1}{2}$ if one of the acid groups contains oxidized sulphur. If two or more carboxylic acid groups are present, the fraction will be greater than $\frac{1}{2}$, even in the presence of a more strongly acidic group, so that the latter will not be detected.

If the unknown is a salt of an alkali metal, the test can still be made by omitting the preliminary titration with alkali. Analyze the unknown for the alkali metal and calculate the number of equivalents of salt present in a 1-gram sample. The hydrochloric acid titration is performed as before, the volume corrected, and the result divided by the volume of 1.0 *N* sodium hydroxide equivalent to the metal present in the sample. The resulting fraction corresponds to that obtained when the unknown is an acid.

Test 4 loses its significance when nitrogen or a halogen is present.

Test 5. **Esters and salts of sulphuric acid.** Boil about 0.1 g. of the unknown with 10 cc. of 1 *N* hydrochloric acid for ten minutes, cool and decant from any undissolved material, and add a drop of a solution of barium chloride. A white precipitate shows that the unknown is an ionized or easily hydrolyzed derivative of sulphuric acid, such as the amine salts or esters of sulphuric acid.

Test 6. Sulphonic acids and esters of sulphurous acid. Fuse 0.5 g. of the unknown with 1 g. of solid potassium hydroxide in a nickel crucible and keep the mass molten for about fifteen minutes; cool and dissolve the reaction product in 50 cc. of water. Neutralize the resulting solution with 1 *N* hydrochloric acid, using litmus paper as an external indicator. Extract the solution with ether. Evaporate the ethereal solution, dissolve the residue in alcohol, and add a drop of ferric chloride solution. A red or purple color shows the presence of a phenol in the products of hydrolysis, and therefore that the unknown is an aromatic compound. Remove the ether from the aqueous residue by evaporation, then pour the residue into a distilling flask, add about 10 cc. of 1 *N* hydrochloric acid, and distill. Collect the first 10 cc. of distillate and add it slowly to 2 cc. of a 1 *N* solution of iodine in aqueous potassium iodide. If the iodine solution is decolorized, potassium sulphite was a product of hydrolysis and the unknown was a sulphonic acid or an ester of sulphurous acid.

Test 7. Sodium bisulphite addition compounds of ketones and aldehydes. Boil 5 g. of the unknown with 50 cc. of 1 *N* potassium carbonate in a small flask which is fitted with a fractionating column and connected to a water-cooled condenser. During the distillation use the procedure outlined in Test 3b, Division I, to obtain evidence of the presence of any organic substances which will distill with steam. Distill until about 10 cc. of liquid has been collected, or as long as there is definite evidence that a substance other than water is coming over. Test 1 cc. of the distillate for aldehydes with Schiff's reagent. Saturate the remainder of the distillate with potassium carbonate, separate any oil that forms and test it for ketone and aldehyde groups (see page 164). Also separate any insoluble but nonvolatile oil from the residue of the distillation, wash it with water, and test it in the same way. If in any of these tests it is shown that an aldehyde or ketone is formed by distilling with sodium carbonate solution, the unknown is a sodium bisulphite addition product of an aldehyde or ketone. This conclusion may be confirmed through the procedure outlined in Test 6 by detecting the presence of sodium bisulphite among the hydrolysis products.

DIVISION IV. COMPOUNDS CONTAINING A HALOGEN

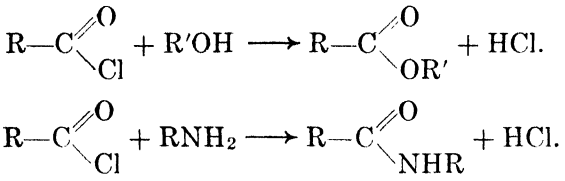
If a substance contains a halogen, the class reactions of the previous divisions are valid, except those involving titrations of acids and hydrolyses to form acids. In these cases the neutralization of the base may be due to the formation of halogen acid. Test 1 in this division is a test to determine whether the halide can hydrolyze so rapidly as to vitiate any test to determine whether the substance is an acid. In general only the acid halides, imido halides, and halide salts of primary, secondary, or tertiary amines can hydrolyze so rapidly as to imitate acids in a titration. Besides these compounds, however, certain alkyl iodides (for example, ethyl iodide) react so rapidly with silver nitrate that they give this test, although they do not hydrolyze rapidly enough to show any acidic properties. The quaternary ammonium and sulphonium halides also respond to Test 1, but these are salts of such strong bases that they do not show appreciable acidic properties.

In Test 2 the formation of halogen ion under more drastic conditions is determined. If halide ion is obtained in this test, then the formation of an acid in Test 3a, Division I, and Test 7, Division II, does not signify the presence of esters or amides. If halogen ion is not formed in this test, then the halogen must be united to an aromatic nucleus or to a carbon which is doubly bonded to another carbon. In the case of the aromatic halides, if nitro groups are ortho or para to the halogen, the halogen will hydrolyze off in this test; in fact, a polynitro derivative, such as picryl chloride, will behave as if it were an acid halide.

Test 1. Salts and easily hydrolyzed halogen derivatives (acid halides and some alkyl halides). Shake a few tenths of a gram of the unknown with 10 cc. of cold water for a few minutes. Remove any insoluble material and add a drop of silver nitrate solution and a drop of 6 *N* chloride-free nitric acid to the aqueous solution. A white or yellow precipitate of silver halide shows that the substance is an ionized or very easily hydrolyzable halide such as a salt or an acid halide, and that the results of Test 1, Division I, of Test 2, Division II, and of Test 4, Division III, should be interpreted as possibly due to the presence of the halogen in the compound.

Test 2. Hydrolyzable halides. Boil in alcohol for fifteen minutes 0.1 g. of the unknown with 10 cc. of a 1 *N* solution of chloride-free sodium hydroxide. Cool the solution and pour it into 50 cc. of distilled water, separate off any insoluble material, acidify the aqueous solution with chloride-free nitric acid, and add a drop of silver nitrate solution. A white or yellow precipitate of silver halide shows the formation of a halogen ion under these conditions, and therefore that tests for esters dependent upon the formation of an acid by hydrolysis are not applicable. If no precipitate is formed in this test, then all the tests in the previous divisions may be used on the unknown, for the halogen in the unknown is attached to an aromatic nucleus or to a carbon atom of an ethylene group.

The acid halides undergo alcoholysis and ammonolysis as well as hydrolysis:



$$R{-}C{\overset{\displaystyle O}{\underset{\displaystyle Cl}{\lessgtr}}} + R'OH \longrightarrow R{-}C{\overset{\displaystyle O}{\underset{\displaystyle OR'}{\lessgtr}}} + HCl.$$

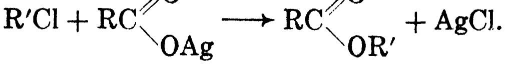
$$R{-}C{\overset{\displaystyle O}{\underset{\displaystyle Cl}{\lessgtr}}} + RNH_2 \longrightarrow R{-}C{\overset{\displaystyle O}{\underset{\displaystyle NHR}{\lessgtr}}} + HCl.$$

These reactions are commonly carried out in the presence of a base such as pyridine or in the presence of sodium hydroxide. They are usually faster than the reaction of hydrolysis, and so may be carried out in the presence of water. The ease of purification of the products (esters and amides) permits the use of the reactions for identification of the acid halides.

The alkyl halides undergo the reactions of hydrolysis, alcoholysis, and ammonolysis less readily than do the acid halides. The last two reactions are used in the preparation of mixed ethers and amines:

$$RCl + R'ONa \longrightarrow ROR' + NaCl.$$
$$RCl + R'NH_2 \longrightarrow RNH_2R'^+ + Cl^-.$$

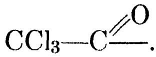
Metallic salts of acids, particularly the silver salts, react with alkyl halides, yielding esters.



$$R'Cl + RC{\overset{\displaystyle O}{\underset{\displaystyle OAg}{\lessgtr}}} \longrightarrow RC{\overset{\displaystyle O}{\underset{\displaystyle OR'}{\lessgtr}}} + AgCl.$$

The formation of an ethylene from a halide and alcoholic potash is a characteristic reaction.

$$\mathrm{R{-}CH_2{-}CH_2{-}Cl + KOH \longrightarrow RCH{=}CH_2 + KCl + H_2O.}$$

Chloroform appears as a product of the alkaline hydrolysis of compounds containing the group  $\mathrm{CCl_3{-}C}\overset{\displaystyle /\!\!/ \mathrm{O}}{-}$. The corresponding bromine and iodine derivatives yield bromoform and iodoform respectively. One of these compounds, therefore, may be found among the reaction products obtained in any investigations in which the substance under examination is treated with alkali. This hydrolytic rupture of a carbon-to-carbon bond is unusual and may be compared with the formation of acids and ketones by the hydrolysis of β-ketonic acids and 1, 3 diketones (see page 159).

Other types of compounds whose formation from alkyl (or acid) halides are modifications of the above reactions are nitrites, nitro compounds, nitrite esters, alcohols, isonitriles, hydroxylamines, substituted amides, phenyl ethers, and substituted malonic esters.

The formation of the various metallic derivatives, with magnesium (Grignard reagent), zinc, mercury, arsenic, and lead, usually involves the use of a halogen derivative.

The aromatic halides and the alkyl halides of the type $\mathrm{RCH{=}CHCl}$ are characterized by inertness of the carbon-halogen bond. As a rule the only reagents which react at all readily with these substances are the metals, as in the formation of the Grignard reagent and in the Fittig reaction. At high temperatures and pressures the usual reactions of hydrolysis and ammonolysis can be carried out.

DIVISION V. COMPOUNDS CONTAINING A METAL

If a metal is present, the substance is probably a metallic salt. It should be quantitatively analyzed for the metal. The metal should be replaced by hydrogen or some other known element or group, and the resulting compound should be investigated.

An organic acid may usually be obtained from its salt by digesting the salt with a mineral acid and dissolving out the organic acid with ether or chloroform. The organic acid is obtained by distilling off the solvent.

If the acid cannot be isolated by the plan just described, and if the salt is that of an alkali metal, an aqueous solution of the salt should be treated with an equivalent of mineral acid, and the organic acid isolated as indicated in Test 3b, Division I. When the salt contains a metal which forms an insoluble salt of a strong acid, the organic acid may be released by digesting the salt with an equivalent quantity of the strong acid. For this purpose barium salts may be treated with sulphuric acid and the organic acid, if soluble in water, may be obtained by evaporating the solution after filtration.

When all the attempts at direct isolation of the acid fail, some other derivative should be made from the salt. Thus an acid chloride may be made by distillation with the theoretical quantity of phosphorus pentachloride, and the acid chloride may be hydrolyzed or may be changed to an amide or to some other easily identified derivative.

Not all organo-metallic derivatives are salts of metals. Some of them are relatively un-ionized substances such as mercury diphenyl, $(C_6H_5)_2Hg$, and tetraethyl lead, $(C_2H_5)_4Pb$. If the metal concerned is highly electropositive, such as zinc or magnesium, the compounds react rapidly with water to form hydrocarbons. Where they are not thus reactive the student should refer to special treatises dealing with the organic compounds of the metal in question, such as "Organic Compounds of Mercury," by Frank C. Whitmore; "Organic Derivatives of Antimony," by Walter G. Christiansen; "Organic Arsenical Compounds," by G. W. Raiziss and Joseph L. Gavron (Chemical Catalog Company).

PART IV. ACIDS, BASES, AND INDICATORS

THE STRENGTH OF AN ACID OR BASE

An acid or base is said to be stronger than another when, at the same molal concentration, the one is ionized to a greater extent than is the other. To avoid confusion, therefore, a concentrated solution should not be referred to as strong nor should a dilute solution be called weak.

Two acids may be compared in strength by determining the degree, or percentage, of ionization of each. Since the degree of ionization is greater in dilute than in more concentrated solutions, the comparison must be made at the same concentration.

Another method of expressing the strength of an acid is by means of the mass-law constant. It is applicable only to relatively weak acids and bases.* An equilibrium exists between the undissociated acid and its ions which may be expressed as follows:

$$RCOOH \rightleftarrows H^+ + RCOO^-.$$

The equilibrium constant K_a is defined as the product of the concentrations of the components on the right side of the equation, divided by the product of the concentrations of the substances on the left side, or

$$K_a = \frac{(H^+)(RCOO^-)}{(RCOOH)},$$

in which the quantities in the parentheses represent the molal concentration of the respective substances.

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* The term *degree of ionization* has lost its significance when applied to strong electrolytes, such as most salts and the mineral acids. Different methods of measuring the degree of ionization of such compounds do not agree, and the results are not useful for quantitative calculations. For present purposes the so-called strong acids and bases, and most salts, will be considered completely ionized in dilute solution.

It must be remembered that when the solution of an acid is titrated, both the hydrogen ion and the undissociated acid are used up. The hydrogen ion concentration is not equivalent to the normal concentration of the acid solution. For weak acids the above equation may be simplified as follows:

Let (A) represent the equivalent concentration (normality) of the acid; then

$$K_a = \frac{(H^+)(RCOO^-)}{(A) - (H^+)}.$$

If no salt of the acid is present, there are equal amounts of H^+ and $RCOO^-$; and if only a small amount of the acid is dissociated, we may neglect (H^+) in comparison with (A) in the denominator. The expression then becomes

$$K_a = \frac{(H^+)^2}{(A)}.$$

The value of (A) is found by titration; the value of (H^+) may be determined in various ways, such as by the use of the hydrogen electrode or by the use of indicators, and hence K_a is calculated with an accuracy dependent upon the above approximations.* This simplification is most useful in calculating the approximate concentration of hydrogen ion when K_a and (A) are known. For instance, K_a for acetic acid is 1.8×10^{-5}. A rough estimate shows this to represent only a few per cent dissociation in a 0.1 N solution of acetic acid. The hydrogen ion concentration of such a solution, therefore, is $\sqrt{1.8 \times 10^{-6}}$, or about 0.0013 N.

Another useful simplification may be used to estimate the hydrogen ion concentration in a mixture of salt and acid, or at any point during a titration. In this case, for a weak acid we may assume that most of the anion comes from the salt and is represented by its concentration. Similarly, the undissociated part of the acid represents the total acid present (normality), since the dissociated portion is small, so that

$$K_a = \frac{(RCOO^-)}{(RCOOH)} \times (H^+) = \frac{(\text{salt})}{(\text{acid})} \times (H^+).$$

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* For nearly all organic acids this simplified formula is accurate to within 5 per cent.

Hence in an equimolal mixture of salt and acid, or when a weak acid is half titrated by a strong base, the ratio salt/acid becomes unity and the hydrogen ion concentration is approximately * equal to the constant K_a.

If the last equation is rearranged, it is seen that the concentration of (H^+) depends on two factors, (1) the magnitude of K_a and (2) the ratio of acid and salt:

$$(H^+) = K_a \frac{(\text{acid})}{(\text{salt})}.$$

The mass law, if applied qualitatively to the equation representing the equilibrium between the undissociated acid and its ions, states that any increase in the concentration of the anion is accompanied by a decrease in the concentration of the hydrogen ion. In other words, the ionization of the acid is repressed. From the above equation it is possible to show that the repression of the ionization for a given increase in the anion concentration depends on the strength of the acid, or on K_a. The method of increasing the concentration of the anion is to add the desired amount of a highly ionized salt of that acid. The weaker the acid, the greater the percentage change in the degree of ionization on the addition of any given amount of its salt. This may be illustrated for the case of a weak acid as follows:

In a solution of a pure acid which is about 1 per cent dissociated, RCOOH is 99 times as large as $RCOO^-$, and the ratio $RCOOH/RCOO^-$ is equal to 99. If to this acid solution we add an amount of the highly ionized salt RCOONa, equal in equivalents to the number of equivalents of acid present, the concentration of $RCOO^-$ becomes approximately the same as that of RCOOH, so that the above ratio becomes unity. A change in the ratio from 99 in pure acid to 1 in the mixture of salt and acid will cause a 99-fold decrease in the hydrogen ion concentration. A 0.1 N solution of acetic acid has a hydrogen ion concen-

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* This simplification is valid within 10 per cent for acids whose dissociation constants lie between $K_a = 1 \times 10^{-3}$ and $K_a = 1 \times 10^{-10}$, provided the salt/acid ratio lies between 0.1 and 9. In the case of phenol ($K_a = 1 \times 10^{-10}$), for instance, the hydrogen ion concentration of a 0.2 N solution which has been titrated to the extent of 99 per cent (which is beyond these limits) with 0.2 N sodium hydroxide is calculated by the simplified formula to be 1×10^{-12} but is actually found by more accurate calculation to be 4×10^{-12}, — an error of 300 per cent.

tration of about 0.0013 *N*. If to one liter of that solution is added one-tenth mol of solid sodium acetate, the hydrogen ion concentration will fall to about 1.8×10^{-5} *N*, or to about 1.3 per cent of its former value. The simplifying assumption used in this case does not always hold. If an acid whose K_a is 10^{-2} were to be so treated, a calculation based upon the above assumptions would lead to a false result, because in that case an appreciable concentration of the anion is present from the acid as well as from the salt, and for the same reason the concentration of undissociated acid cannot be assumed equivalent to the normality of the acid. A calculation can be made, however, without these assumptions. Using the concentrations and procedures outlined above for acetic acid, the hydrogen ion concentration would be found to change from 2.7×10^{-2} *N* in a 0.1 *N* solution of the pure acid to 0.85×10^{-2} *N* in the mixture of salt and acid, each 0.1 *N*. With this stronger acid the hydrogen ion concentration falls to about 31 per cent of its former value. A similar calculation for a very strong acid, based on the mass law, would be meaningless, as the mass law is not followed by strong electrolytes. In such a case, however, the addition of the salt is found to have little or no effect on the apparent degree of dissociation of the acid. The relative effect on the hydrogen ion and hydroxide ion concentrations due to partial neutralization of various acids and bases can best be seen by comparing the titration curves shown in Fig. 33.

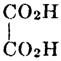
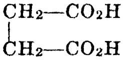
The table on the opposite page gives the dissociation constants of some typical organic acids, with the approximate hydrogen ion concentration of a 0.1 *M* solution of each.

The behavior of an organic base, or amine, is identical with that of ammonia as a base. The primary, secondary, and tertiary aliphatic amines are slightly stronger bases than ammonia, and the aryl (benzene) derivatives are much weaker. Quaternary bases are highly ionized and are to be regarded as strong electrolytes.

The mass-law expression for the action of an amine as a base may take a variety of forms, according to the equation used. We may write

$$R_3N + H_2O \rightleftharpoons R_3NHOH \rightleftharpoons R_3NH^+ + OH^-.$$

DISSOCIATION CONSTANTS OF SOME ORGANIC ACIDS

NAME	FORMULA	K_a*	H^+ CONCENTRATION IN A 0.1 M SOLUTION
Carbonic	H_2CO_3	$K_1 = 3 \times 10^{-7}$ $K_2 = 6 \times 10^{-11}$	1.7×10^{-4} ——
Formic	HCO_2H	2.14×10^{-4}	4.5×10^{-3}
Acetic	CH_3CO_2H	1.8×10^{-5}	1.3×10^{-3}
Propionic	$C_2H_5CO_2H$	1.4×10^{-5}	1.2×10^{-3}
Butyric	$C_3H_7CO_2H$	1.5×10^{-5}	1.2×10^{-3}
Lactic	$CH_3—CHOH—CO_2H$	1.4×10^{-4}	3.7×10^{-3}
Chloracetic	$Cl—CH_2—CO_2H$	1.55×10^{-3}	11.5×10^{-3}
Phenylacetic	$C_6H_5—CH_2—CO_2H$	2.2×10^{-5}	1.5×10^{-3}
Oxalic	 $CO_2H—CO_2H$	$K_1 = 3.8 \times 10^{-2}$ $K_2 = 4.9 \times 10^{-5}$	45×10^{-3} ——
Malonic	$CH_2(CO_2H)_2$	$K_1 = 1.6 \times 10^{-3}$ $K_2 = 2.1 \times 10^{-6}$	12×10^{-3} ——
Succinic	 $CH_2—CO_2H—CH_2—CO_2H$	$K_1 = 6.6 \times 10^{-5}$ $K_2 = 2.7 \times 10^{-6}$	2.6×10^{-3} ——
Benzoic	$C_6H_5—CO_2H$	6.6×10^{-5}	2.6×10^{-3}
Bromobenzoic 1 : 3	$C_6H_4Br—CO_2H$	1.37×10^{-4}	3.7×10^{-3}
Phenylsulphonic	$C_6H_5—SO_3H$	2×10^{-1}	73×10^{-3}
Phenol	C_6H_5OH	1×10^{-10}	3×10^{-6}

in which two equilibria are involved, and the OH^- concentration depends on both. It is impossible to distinguish satisfactorily between the amine present as R_3N (simply dissolved) and as R_3NHOH. The first equilibrium cannot be evaluated. It is customary, therefore, to represent the equilibrium constant as follows:

$$K_b = \frac{(R_3NH^+)(OH^-)}{(R_3N) + (R_3NHOH)}.$$

The two factors in the denominator represent all the amine present not in the ionic form. If the base is weak, the same simplifications may be adopted as in the case of the acids. If (B) is the concentration of the weak base,

$$K_b = \frac{(OH^-)(R_3NH^+)}{(B) - (OH^-)}.$$

---

* The acids referred to by K_1 and K_2 in the case of dibasic acids are the free acid and the acid salt respectively. Thus a 0.1 M solution of oxalic acid contains 9.0 g. per liter and has a hydrogen ion concentration of 45×10^{-3} normal. K_2, however, refers to such a salt as sodium acid oxalate, $NaHC_2O_4$. If the two acid constants are far different in magnitude, the two acids ($H_2C_2O_4$ and $HC_2O_4^-$ in this instance) may be treated as separate substances; but if they are similar in magnitude, as in

If no salt of the base is present, then (OH^-) is equal to (R_3NH^+). If the base is weak, (OH^-) is small as compared with (B), so that

$$K_b = \frac{(OH^-)^2}{(B)} \text{ and } (OH^-) = \sqrt{K_b\,(B)}.$$

If a salt of the base is present, or if the base has been partially neutralized by a strong acid,

$$K_b = \frac{(R_3NH^+)}{(\text{base})} \times (OH^-) = \frac{(\text{salt})}{(\text{base})} \times (OH^-).$$

The following table gives the value of K_b for some typical organic bases:

DISSOCIATION CONSTANTS OF SOME ORGANIC BASES

NAME	FORMULA	K_b	CONCENTRATION OF OH^- IN A 0.1 M SOLUTION
Ammonia	NH_3	1.9×10^{-5}	1.4×10^{-3}
Hydrazine	$H_2N—NH_2$	$K_1 = 3 \times 10^{-6}$	0.55×10^{-3}
		$K_2 = 1 \times 10^{-14}$	——
Hydroxylamine . .	H_2NOH	6.6×10^{-9}	2.6×10^{-5}
Dimethylamine . .	$(CH_3)_2NH$	7.4×10^{-4}	8.6×10^{-3}
Trimethylamine .	$(CH_3)_3N$	7.4×10^{-5}	2.7×10^{-3}
Butylamine (sec.) . .	$(C_3H_7)CH_2NH_2$	7.4×10^{-4}	8.6×10^{-3}
Triethylamine . .	$(C_2H_5)_3N$	6.4×10^{-4}	8.0×10^{-3}
Diethylamine . . .	$(C_2H_5)_2NH$	1.3×10^{-3}	11×10^{-3}
Benzylamine	$C_6H_5CH_2NH_2$	2.4×10^{-5}	1.5×10^{-3}
Aniline	$C_6H_5NH_2$	4.6×10^{-10}	6.8×10^{-6}
Ethyl aniline	$C_6H_5—NH—C_2H_5$	4×10^{-10}	6.3×10^{-6}
β-Naphthylamine . .	$C_{10}H_7NH_2$	1×10^{-10}	3.1×10^{-6}
Toluidine 1 : 2 . .	$C_6H_4CH_3NH_2$	2.9×10^{-10}	5.4×10^{-6}
Phenyldiazonium hydroxide	$C_6H_5N_2OH$	1.2×10^{-3}	1.1×10^{-2}
Urea	$CO(NH_2)_2$	$K_1 = 1.5 \times 10^{-14}$	*
Acetamide	CH_3CONH_2	3×10^{-15}	*
Acetoxime	$CH_3CH{=}NOH$	6.5×10^{-13}	*
Acetanilide	$CH_3CO—NHC_6H_5$	4×10^{-14}	*
Pyridine	C_5H_5N	2.3×10^{-9}	1.5×10^{-5}
Piperidine	$C_5H_{11}N$	1.6×10^{-3}	1.2×10^{-2}

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the case of succinic acid, the second acid would be appreciably neutralized on titration before the first was completely neutralized, so that the simplified formulas cannot be applied for either acid, except at the very beginning, when the dibasic acid is present, and near the end, when all the acid is in the form of ions.

* The values of these basic constants indicate only the order of magnitude and may be in error by as much as a power of ten. Solutions of such substances are practically neutral. They do form salts with acids and hence are basic, but the salts in water are almost completely hydrolyzed.

THE NATURE OF INDICATORS

An indicator is used during the titration of an acid by a base to determine the point at which the number of equivalents of base just equals the number of equivalents of acid present. The resulting solution contains the normal salt of that acid and base, and could as well be prepared from the solid salt. Suppose the acid were acetic and the base sodium hydroxide. The true end point would indicate a solution of sodium acetate, but since the solution of such a salt is alkaline through hydrolysis, the true end point is really on the alkaline side of a neutral solution. An indicator which changed at the true neutral point (hydrogen ion concentration of pure water) would in such a case give an end point with less base present than that actually necessary to form the neutral salt. Correspondingly the titration of a weak base by hydrochloric acid would require an indicator whose color change takes place on the acid side of the true neutral point.

TABLE OF INDICATORS

INDICATOR	*p*H RANGE*	RANGE OF (H^+)
Methyl violet	1.0 – 3.2	$1.0 \times 10^{-1} - 6.3 \times 10^{-4}$
Thymol blue	1.2 – 2.8	$6.3 \times 10^{-2} - 1.6 \times 10^{-3}$
Bromophenol blue	3.0 – 4.6	$1.0 \times 10^{-3} - 2.5 \times 10^{-5}$
Methyl orange	3.1 – 4.4	$7.9 \times 10^{-4} - 4.0 \times 10^{-5}$
Congo red	3 – 5	$1.0 \times 10^{-3} - 1.0 \times 10^{-5}$
Methyl red	4.4 – 6.0	$4.0 \times 10^{-5} - 1.0 \times 10^{-6}$
Litmus	4.5 – 8.3	$3.2 \times 10^{-5} - 5.0 \times 10^{-9}$
p-Nitrophenol	5.0 – 7.0	$1.0 \times 10^{-5} - 1.0 \times 10^{-7}$
Bromocresol purple	5.2 – 6.8	$6.3 \times 10^{-6} - 1.6 \times 10^{-7}$
Bromothymol blue	6.0 – 7.6	$1.0 \times 10^{-6} - 2.5 \times 10^{-8}$
Phenol red	6.8 – 8.4	$1.6 \times 10^{-7} - 4.0 \times 10^{-9}$
Rosolic acid	6.9 – 8.0	$1.3 \times 10^{-7} - 1.0 \times 10^{-8}$
Cresol red	7.2 – 8.8	$6.3 \times 10^{-8} - 1.6 \times 10^{-9}$
Thymol blue	8.0 – 9.6	$1.0 \times 10^{-8} - 2.5 \times 10^{-10}$
Cresolphthalein	8.2 – 9.8	$6.3 \times 10^{-9} - 1.6 \times 10^{-10}$
Phenolphthalein	8.3 – 10.0	$5.0 \times 10^{-9} - 1.0 \times 10^{-10}$
Thymolphthalein	9.3 – 10.5	$5.0 \times 10^{-10} - 3.2 \times 10^{-11}$
Tropæölin O	11.1 – 12.7	$7.9 \times 10^{-12} - 2.0 \times 10^{-13}$

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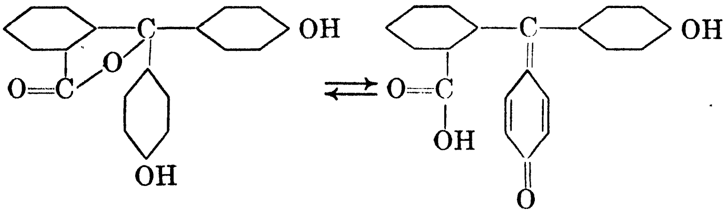
* The term *p*H is defined as follows:

$$pH = \log_{10} \frac{1}{(H^+)} = -\log_{10} (H^+).$$

The use of the logarithm of the H+ ion concentration facilitates the plotting of this variable against factors dependent on it.

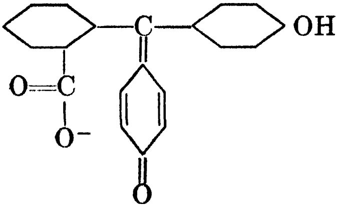
Indicators may be obtained which change color at almost any desired range of hydrogen ion concentration. The table of indicators on page 251 gives a list of some common indicators and the range of hydrogen ion concentration over which a color change occurs.

The reason that different indicators change color at different hydrogen ion concentrations is that indicators are acids and bases, and the color changes are accompanied by the formation of salts of the indicators themselves. If the indicator is a very weak acid ($K_a = 10^{-9}$), salt formation is complete only in the presence of a high concentration of hydroxide ions. If it is a very weak base, an acid solution will be necessary to cause appreciable salt formation and change of color. It need not be inferred, however, that salt (or ion) formation is all that takes place when an indicator changes color. Most indicators, in addition to being acids or bases (or salts), are capable of tautomeric transformation into other configurations, such as the change of the lactone form of phenolphthalein (I) into the carboxylic acid (II).

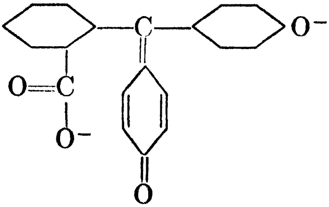


I II

Alkali reacts with phenolphthalein to form salts whose anions have the structures III and IV. The highly colored form of the indicator is believed to correspond to structure IV.



III



IV

Now if one of the tautomers is a stronger acid than the other, alkali will shift the tautomeric equilibrium so as to form the salt of the stronger acid. The change in structure may be accompanied by the appearance of a change in color. The same is true of basic indicators in forming salts with acids.

From the discussion of the strengths of acids and bases (p. 245) it would seem possible to calculate the percentage of salt formation of the indicator at any given hydrogen ion concentration if the strength of the indicator as an acid or base is known. The hydrogen ion concentration required for conversion of half the acid to the salt is numerically equal to the dissociation constant. If the acid is colorless and the salt colored, we may determine the dissociation constant as follows: Two solutions of the indicator of the same molal concentration are superimposed so that a beam of sunlight passes through both. One is made distinctly alkaline and the other acidic. The effect of looking through both solutions at once is the same as looking through an equal amount of indicator in which half is the free acid and half the salt. Then if an acid solution of the indicator is titrated with a base until the color matches the color of the superimposed solutions, the half conversion point has been reached. The hydrogen ion concentration of the resulting solution may be determined by means of a hydrogen electrode, and K_a for the indicator may then be determined. But reference to the outline of the tautomeric transformation of phenolphthalein (p. 252) raises the question, To which tautomer, I or II, does the measured K_a refer? It seems obvious that if a means of determining K_a had been used which did not utilize the color of the substance, an entirely different value might have been obtained, since the neutralization of form II does not presumably cause much change in color. It is apparent, therefore, that K_a measured as above refers neither to I nor to II alone as the acid in question, but to the *apparent* strength of the substance as an acid when it is to be used as an indicator. The equilibrium mixture of the two or more tautomers is the acid in question. This does not in any way change the simple mathematical treatment of the indicator as an acid or a base, provided that equilibrium is always established between the various tautomers, and provided that the molecular transformations do not involve dissociation of one colorless molecule into two or more colored molecules, or the reverse. The strength of the individual tautomers as acids or the relative amount of each in solution need not be known. The mixture may be treated as a single compound of an apparent acidity or basicity. This may be illustrated by the case of ammonia. Ammonia itself may unite with hydrogen ion to form ammonium ion, or ammonium hydroxide may react with hydrogen ion. For each of these reactions an equilibrium constant might be obtained. There is also an equilibrium between the free ammonia and the ammonium hydroxide to consider. Since we cannot evaluate these various constants, the usual treatment is to obtain an *apparent* constant K_b for ammonia, assuming equilibrium between the two modifications of the base and water. Likewise there may be several unknown tautomeric forms of an ordinary carboxylic acid, but that does not prevent treatment of such a compound as a single type of molecule.

The visibility and sharpness of the color change depends on a great many factors, and the student is referred to other works for a complete discussion of them. It is necessary to bear in mind, however, the connection between the fact that indicators behave as acids or bases and the necessity of speaking of a *range* of hydrogen ion concentrations within which a color change occurs. No indicator changes color sharply at a given hydrogen ion concentration. As an acid or base of definite strength it would be neutralized to a definite extent at any given hydrogen ion concentration. The amount to be neutralized before a color change is visible depends on the concentration of the indicator and the intensity of its color. In one case perhaps the neutralization of 5 per cent would cause a perceptible change, in another perhaps 50 per cent would be necessary. It is conceivable that in a very dilute solution of phenolphthalein all of the indicator would have to be converted to the colored ion to make the change visible. At twice that concentration only half conversion would be necessary. But to go from zero neutralization of an acid to half, and from half to complete neutralization, involves fairly large changes in the hydrogen ion concentration. This change in the hydrogen ion concentration necessary to neutralize enough of the indicator to cause an appreciable color change is known as the color range of the indicator.

The concentration of hydrogen ion at which the indicator is 50 per cent neutralized depends on its strength as an acid or a base, and may be calculated from its dissociation constant by using the simplified formulas given in a previous section. If, then, in a list of indicators there are strong and weak acids, strong and weak bases, and salts of all possible combinations of them, it is readily understood why the significant color changes do not all occur at the same hydrogen ion concentration and why, as a rule, only a very few indicators can be used in the titration of any particular acid or base. The question of the choice of an indicator for a specific purpose will be considered in the next section.

THE TITRATION OF ACIDS AND BASES AND THE DETERMINATION OF EQUIVALENT WEIGHTS

One equivalent of any acid will react with one equivalent of any base to form one equivalent of the corresponding salt. The process of titration enables us to treat an unknown number of equivalents of bases (or acids) with a known number of equivalents of acid (or base) and to determine when the reagents are present in equivalent proportions. Usually this is carried out by preparing a standard solution of one of the reagents of known equivalent concentration, or normality, and determining the volume of this solution which is necessary to react in equivalent proportions with a given amount of the unknown reagent. Thus, if 19.50 cc. of a 0.100 *N* solution of sodium hydroxide exactly neutralizes 0.100 g. of an unknown acid, there must be 0.00195 of an equivalent of the acid in 0.100 g. There are 51.3 g. in one equivalent of the acid. If 15.00 cc. of a solution of the acid neutralizes 19.50 cc. of a 0.100 *N* solution of sodium hydroxide, then 15.0 cc. contains 0.00195 of an equivalent, and one liter contains 0.130 of an equivalent.

The uncertainty in the procedure is the determination of the end point, that is, the point at which equivalent amounts of the reagents have been put together. At the true end point a solution of the normal salt should have been formed. This solution, however, may not be truly neutral. In one sense the acid and alkali are mutually neutralized, but the salt solution may be acidic or basic, or at any intermediate point, depending upon the character of the acid and base and whether the basic or the acidic hydrolysis of the salt predominates. Therefore in titrating an unknown base with a known strong acid the determination of the true end point depends upon a knowledge of the base strength of the unknown, a prediction as to the hydrogen ion concentration in a solution of the normal salt, and the proper choice of indicator to detect when this hydrogen ion concentration is reached during the titration.

The equation of hydrolysis of a salt AB may be written

$$\begin{array}{ll} & A^+ + B^- + H_2O \longrightarrow A^+ + BOH + H^+ \\ \text{or} & A^+ + B^- + H_2O \longrightarrow AH + B^+ + OH^- \\ \text{or} & A^+ + B^- + H_2O \longrightarrow AH + BOH. \end{array}$$

If the first and second reactions take place to an equal extent, no excess of H^+ or OH^- is produced, and the result may be represented by the third equation. If K_h represents the mass-law constant for the hydrolysis, K_w the dissociation constant of water, and K_a and K_b the dissociation constants of acid and base respectively (p. 245), we may write, for the three reactions,

$$K'_h = \frac{K_w}{K_b}, \quad K''_h = \frac{K_w}{K_a}, \quad K'''_h = \frac{K_w}{K_a \times K_b}.$$

The hydrogen ion concentration at the true end point for acetic acid titrated by sodium hydroxide may be calculated as an example. The hydrolysis of sodium acetate is of the second type, and K_a for acetic acid is equal to 1.80×10^{-5}. Since

$$K_w = (H^+)(OH^-) = 1 \times 10^{-14},$$

then

$$K_h = \frac{1 \times 10^{-14}}{1.8 \times 10^{-5}} = 0.555 \times 10^{-9}.$$

If the sodium acetate at the end of the titration is 0.1 *M*, and if we neglect the hydrolyzed portion in estimating the concentration of the salt, we may write

$$K_h = \frac{(\mathrm{OH}^-)^2}{1 \times 10^{-1}} = 0.555 \times 10^{-9},$$

and

$$(\mathrm{OH}^-) = 0.745 \times 10^{-5},$$

or

$$(\mathrm{H}^+) = \frac{1 \times 10^{-14}}{0.745 \times 10^{-5}} = 1.34 \times 10^{-9}.$$

To detect this concentration of hydrogen ion an indicator changing at about $(\mathrm{H}^+) = 10^{-9}$ is necessary. Phenolphthalein is such an indicator, and as a matter of fact acetic acid may be accurately titrated with sodium hydroxide by using phenolphthalein.

The question as to how close to the desired point the indicator must change can best be answered by a consideration of how rapidly the hydrogen ion concentration changes not only at the true end point but at all points during the titration. We may plot the concentration of hydrogen ion against the amounts of acid or alkali added during the titration. Since, however, the hydrogen ion concentration may change over a billionfold during a titration, the logarithm, or the negative of the logarithm, of the hydrogen ion concentration is plotted instead. These quantities have the additional advantage of being linear functions of the potential of the hydrogen electrode. The electromotive force of the hydrogen electrode is proportional to the logarithm of the hydrogen ion concentration, so that the shape of the curve is not altered by substituting the potential reading of the electrode for the logarithm of the hydrogen ion concentration in the actual plot. This logarithm function was designated by Sorensen as *p*H and is defined as

$$p\mathrm{H} = \log_{10} \frac{1}{(\mathrm{H}^+)} = -\log_{10}(\mathrm{H}^+).$$

Several typical titration curves are given in Fig. 33. In constructing the curves it is considered that a 0.2 *N* solution of acid or base is being neutralized by the addition of a 0.2 *N* solution of a strong base or acid respectively. The *p*H of the solution during the titration is plotted against the fractional degree of neutralization. The reverse process is also indicated on the plot, namely, the addition to the salt solution of a strong acid or base. It must be remembered that the actual *p*H of such solutions is a function not only of the dissociation constants of the various electrolytes (including water) but also of their actual concentrations.

Three points on each curve are of particular interest. The slope of the curve at any point gives the rate of change of the logarithm of the hydrogen ion concentration as reagent is added, and it is seen that in all the cases given this rate of change is high at the point where the acid and base are present in equivalent quantities. The point where the rate of change is greatest represents the true end point.* When a strong acid is titrated by a strong base, the curve is symmetrical about the true neutral point, $(H^+) = 10^{-7}$, and is steep over a wide range of *p*H; that is, very little reagent is necessary to cause a tremendous change in *p*H at the end point. If the substance being titrated is a weak electrolyte, the true end point is in the acid or basic range and the curve is not steep over a wide range of *p*H.

A second point of interest in the titration curves is at the beginning of the titration. Here again is a marked difference in the slope of the curves, depending upon the strength of the acid or base that is titrated. The relatively great change in the *p*H of the solution when a weak acid is being titrated or when a weak base is being titrated, as opposed to the results obtained with strong acids and bases, is due to the repression of the ionization of the weak electrolyte by the production of its ions. For example, the partial neutralization of acetic acid introduces a relatively high concentration of acetate ions through the salt formed, and the ionization of the remaining acid is repressed (see page 247). On the other hand, sulphate ions have very little effect upon the degree of ionization of sulphuric acid.

A third point of interest in these curves is the point representing half neutralization. If the substance titrated is a weak electrolyte, the hydrogen ion concentration (or, for a base,

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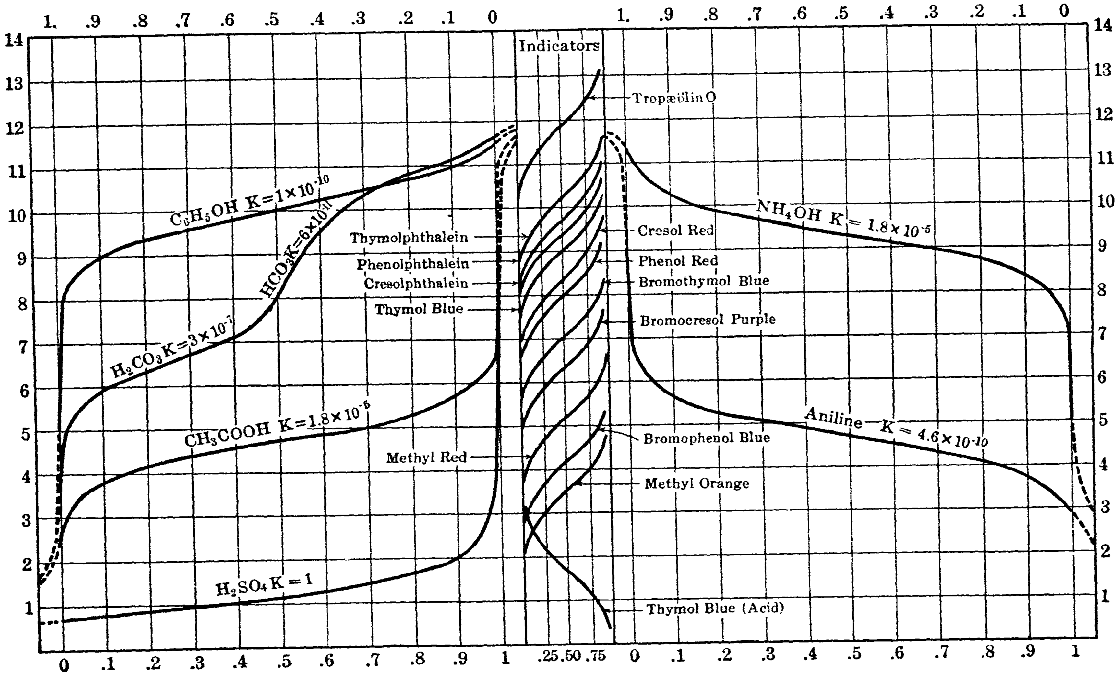
* Eastman, *J. Am. Chem. Soc.*, **47**, 332 (1925).



Indicators
C_6H_5OH K=1×10^{-10}
HCO_3 K=6×10^{-11}
H_2CO_3 K=3×10^{-7}
CH_3COOH K=1.8×10^{-5}
H_2SO_4 K=1
NH_4OH K= 1.8×10^{-5}
Aniline K= 4.6×10^{-10}
Tropæolin O
Thymolphthalein
Phenolphthalein
Cresolphthalein
Thymol Blue
Methyl Red
Cresol Red
Phenol Red
Bromothymol Blue
Bromocresol Purple
Bromophenol Blue
Methyl Orange
Thymol Blue (Acid)
1. .9 .8 .7 .6 .5 .4 .3 .2 .1 0
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1
.25 .50 .75
14 13 12 11 10 9 8 7 6 5 4 3 2 1

FIG. 33

hydroxide ion concentration) is approximately equal to the dissociation constant of the substance as an acid or base (see page 247). Moreover, the curves for weak electrolytes particularly are flat at this point. This means that considerable amounts of acid or base could be added to the solution without marked change in the *p*H of the solution.

Choice of indicator. We have already seen that an indicator, to be useful for titration, must change near the *p*H of a solution of the normal salt, which in turn depends on the strength of the acid and base concerned. In the case of sulphuric acid and sodium hydroxide, however, the portion of the curve between *p*H 3 and *p*H 10 corresponds to the addition of but a very small amount of alkali. Either methyl orange or phenolphthalein could be used without serious error. If the curve in the neighborhood of the true end point is not steep, as in the case of aniline titrated with a strong acid, there will be less choice in the selection of the indicator, since a slight variation from one equivalent in the amount of reagent added corresponds to a very small variation in the *p*H of the solution. The indicator to be useful in such a case must change color in a *p*H range very close to the desired point. Hence if we calculate that in a solution of aniline hydrochloride the hydrogen ion concentration is 1.5×10^{-3} N ($p\text{H} = 2.82$), we may know that a serious error would be involved if the indicator chosen changed closer to $p\text{H} = 4$ than to $p\text{H} = 3$.

Indicators are weak acids or bases, and their salts differ in color from the un-ionized substances. A titration curve for an indicator as an acid or a base could be constructed. It might look like the curve for acetic acid, phenol or aniline, according to the strength of the indicator as an acid or a base. When used as an indicator, however, it is not completely neutralized, because the eye detects the appearance of color or a change in color very readily; and as soon as a part of the indicator is neutralized, the first color change obscures the succeeding changes. As soon as a small fraction is neutralized, the color appears, but it is precisely at this point that the indicator titration curve flattens out. A slight change in *p*H beyond this causes a relatively large neutralization of the indicator, say from 5 per cent to 50 per cent, and from a faint coloration the solution becomes deeply colored. If this change in *p*H takes place rapidly, in point of time or in amount of reagent added, the end point is sharp. An indicator is used in such small amount that it furnishes only a minute fraction of the total acid or base present during a titration, and hence the *p*H of the solutions at any point depends only on the relative amounts of the main reagents. If the steep portion of the titration curve covers the *p*H range of the flat portion of the indicator curve, then at the end point a small amount of added reagent not only causes a great change in the *p*H of the solution but also neutralizes a large proportion of the indicator present, and hence produces a marked color change. Thus, if aniline salts or acetates were colored, aniline and acetic acid would be satisfactory indicators for the sulphuric acid-sodium hydroxide titration. Phenol likewise could be used, if its salts were colored, for an acetic acid titration with sodium hydroxide.

When a reasonable degree of accuracy is desired, other factors enter besides those already considered. The color range of an indicator may be altered by the presence of salts. This is called a salt effect and is not entirely understood. In case of doubt an indicator which theoretically should be satisfactory must be tried under the conditions of the experiment with known materials. Such an operation is called performing a blank test on the indicator. Another limiting factor is the personal equation. The ability to observe a color change or difference in color varies with individuals, even when the optimum conditions for observance, with respect to concentration of indicator, strength of standard solutions, incident light, and volume of solution to be titrated, are present. A rapid change in point of time is desirable. One drop of reagent should cause an unmistakable change. If two, three, or four drops are necessary, and time elapses between drops, the color change may be so gradual that the memory cannot be depended upon to detect the change. A stronger reagent, more rapid addition of the reagent, or smaller volume of solution to be titrated may assist in overcoming this difficulty. Usually a color standard in a vessel of the same shape is prepared, and the solutions are calibrated with respect to that particular shade. With that present a direct comparison of color is possible.

Error in the end point. An error in the end point is unavoidable. To produce a change of color in the indicator a change of *p*H must be brought about, and this in turn demands a finite amount of reagent more or less than the true amount. Thus even in the case of the sulphuric acid-sodium hydroxide titration, where the end point is approximately at $p\text{H} = 7$, it is practically impossible to bring the solution exactly to the true end point. The percentage error may be minute, but an actual error is always involved. When weak acids or bases are titrated, one drop does not produce much change in *p*H at the end point, and so there is no great color change. Even with a color standard one may be undecided as to whether the color is matched or exceeded. Such a difficulty is partly mechanical but presents an error inherent in the titration method. Limitation of the magnitude of this error is dependent upon the use of a standardized procedure. It is necessary to run blanks, using color standards if necessary, using the same total volume of solution, and approaching the change of color from the same side. Repeated blanks with known materials indicate the reproducibility of the results and even warrant correction factors to eliminate the error. For instance, if different samples of pure oxalic acid, of 0.2000 g. each, were titrated and the results agreed within 0.2 per cent, but the average was in error by 1.0 per cent with the theoretical, a correction factor of 1.0 per cent would be justifiable on a sample of unknown purity run under identical conditions. This is sometimes expressed as a restandardization of the alkali used and illustrates the necessity of standardizing the solutions by a method as nearly identical as possible with the process in which the solution is to be used. In any event the cause of an error in the end point should be ascertained and the error eliminated if possible. If it is not possible, the magnitude of the error should be estimated.

Use of different end points. Much can be learned about a substance by determining its reaction on titration to two different end points. Suppose one sample of acetic acid were titrated, using methyl orange, and another sample titrated, using phenolphthalein. The fact that the results differed greatly, combined with a very poor end point in the methyl orange titration, would suggest a titration curve of a very definite shape and position, and hence would furnish a real clue as to the nature of the compound.

Determination of equivalent weights. The equivalent weight of an acid is defined as that weight of the substance which contains one gram-atom of hydrogen capable of reacting as hydrogen ion. Correspondingly, one equivalent of a base is defined as that weight of a substance which will react completely with one equivalent of acid. The determination of the equivalent weight of an acid or base by titration, therefore, is dependent upon detection of the point at which the reagents are present in equivalent quantities. In a sense the reaction is seldom complete, since at the true end point either hydrogen or hydroxide ion is usually in excess. Therefore the accuracy of the determination is dependent upon the usual mechanical errors of weighing and of measurement of volume, together with the error in the end point. Where great accuracy is desired, the titration method cannot be used. In this case the hydrogen (or hydroxyl) is replaced by an element or radical whose quantitative determination can be made more accurate, as in the determination of silver in the pure silver salt, the determination of halide or sulphate in the salt of an amine, or of platinum or gold in the corresponding double salt with amines.

Percentage error. A distinction must be drawn between error and percentage error. If the true equivalent weight of an acid is 60 g. but the average of a number of determinations indicates 59.5 g., the actual error is 0.5 g. and the percentage error 0.83 per cent. Similarly, if a substance contains 40.0 per cent carbon but a combustion results in the value 40.3 per cent, an error of 0.3 per cent is involved, but the percentage error in the determination is $0.3/40 \times 100 = 0.75$ per cent. The terms *actual error* and *deviation* are sometimes used for the term *error* to avoid ambiguity when the quantity in question is a percentage.

Errors may arise from a variety of causes and may be classified in two distinct groups as systematic errors and erratic errors.

Systematic errors. There are errors whose sources are known and which may, in part at least, be eliminated, or for which corrections may be made. Examples of this type of error are inequality in the length of the balance arms, incorrect weights, the adsorption of impurities by a precipitate, and the overrunning of an end point in a titration. These are characterized as leading consistently to a larger or smaller result if the experimental method is unchanged.

Erratic errors. There are errors which lie beyond the control of the experimenter. They follow the law of chance and there is equal probability that any given observation may be greater or less than the true value. Examples of this type of error are the estimation of a scale division or rest point and the sudden fluctuation of temperature.

The determination of the probable error in any given observation is at times a complex problem. The observer must be aware of any systematic errors entering into the observation and their magnitude. He must also know what erratic errors are involved and must judge from the reproducibility of his results the probable error in any one isolated observation. For instance, the determination of a volume may involve a burette calibration, which in turn may involve one or more weighings. The assumption of a calibration introduces a systematic error in all subsequent use of the instrument, but in the calibration itself there was an erratic error due to the weighings.

If we may assume an independent estimation of the error in each observation, we may proceed to show how these errors are related when the results of several observations are used in a calculation. It may be shown that if a result A is to be calculated as a product or a quotient from measurements B and C, and the percentage error in each is small, the percentage errors are related as shown below, where a, b, and c are the actual errors, respectively, in A, B, and C. In words, the percentage error in a product or a quotient *may be* the square root of the sum of the squares of the percentage errors of the quantities involved in the product, or,

$$(1)\ \left.\begin{array}{l}\text{If } A = B \times C \\ \text{or} \\ \text{If } A = \dfrac{B}{C}\end{array}\right\}\text{then } \frac{a}{A} \times 100 = \sqrt{\left(\frac{b}{B} \times 100\right)^2 + \left(\frac{c}{C} \times 100\right)^2}.$$

The individual errors may be of such a character as to counterbalance each other to some extent. It then happens that very close agreement with a theoretical result is sometimes obtained in spite of relatively large errors inherent in the process. Similarly, very close agreement in duplicate determinations is often found, but the average may be greatly in error because the individual errors are consistently in the same direction. An estimation of the possible total error by this means assumes that the individual errors are independent of each other, and the practice of placing reliance on an average of several determinations assumes that any given error will be in one direction as often as in the other. Neither of these assumptions holds in all cases. It is necessary, however, to estimate the magnitude of all possible errors in an operation, and from them to determine the probable error in the final result.

Two very important cases to consider involve the sum and the difference of two quantities. In these cases the percentage error in the measured quantity is not as important as the actual magnitude of that quantity. Using the same notation as above, we may write

$$\text{(2) If } A = B + C, \text{ then } \frac{a}{A} \times 100 = \frac{\sqrt{b^2 + c^2}}{B + C} \times 100.$$

$$\text{(3) If } A = B - C, \text{ then } \frac{a}{A} \times 100 = \frac{\sqrt{b^2 + c^2}}{B - C} \times 100.$$

If in (2) B is very small compared with C, the *percentage* error in B could be very large without introducing a very large error in A. Likewise in (3) the actual errors b and c could both be small; but if, in addition, the factor $B - C$ were small, the percentage error in A could be very large.

As an example suppose we consider the determination of an equivalent weight. A 0.200 g. sample is weighed to 1 mg. and titrated with 0.100 N sodium hydroxide which is accurate to 0.5 per cent. The end point is not very sharp, being in doubt by two drops, or 0.10 cc. The burette reading is 13.35 cc. as taken and is probably accurate to 0.02 cc. The equivalent weight is calculated to be $\frac{0.200}{0.00135} = 148$ g. The denominator is the product of two quantities, the normality and volume of the alkali. The first is in doubt by 0.5 per cent and the second by 0.74 per cent if, in view of the large uncertainty in the end point, we neglect the error in the burette reading. The most probable error in the equivalent weight will be $\sqrt{0.5^2 + 0.5^2 + 0.74^2} = 1.02$ per cent. Of these errors only the error in weighing could reasonably be expected to deviate in direction in successive trials if the same solution and procedure were used. Much greater accuracy could be obtained by using a larger sample, since the individual actual errors would remain of the same magnitude.

In general, then, we may state that $E = \sqrt{e_1{}^2 + e_2{}^2 + e_3{}^2 + \cdots}$, where E is the resultant error due to the errors e_1, e_2, e_3, etc. Where the calculated quantity is the result of the addition or subtraction of two or more quantities, E and e_1, e_2, e_3, etc. are expressed in the same units as the quantities used (grams, cubic centimeters, etc.). Where the calculated quantity is the result of multiplication or division, E and e_1, e_2, e_3, etc. are represented as percentages.

PART V. QUANTITATIVE ANALYSIS

THE DETERMINATION OF CARBON AND HYDROGEN IN COMPOUNDS CONTAINING CARBON, HYDROGEN, AND OXYGEN

Liebig's method.* Liebig's method for the determination of carbon and hydrogen depends on the complete combustion of the substance to water and carbon dioxide and the determination of the weight of each by absorption in weighed amounts of calcium chloride and potassium hydroxide respectively.

The materials needed for this determination are pure, dry air and oxygen free from carbon dioxide, under about two feet of water pressure; a furnace and combustion tube; a U tube filled with porous calcium chloride for the absorption of water; and a gas absorber containing a 40 per cent solution of potassium hydroxide for the absorption of carbon dioxide.

A very satisfactory stream of air or oxygen under the required pressure may be obtained by using an ordinary gasometer which holds enough of the gas for at least one combustion. For oxygen the gasometer may be filled from a commercial oxygen cylinder, or the oxygen may be generated by means of sodium peroxide and water. The streams of air and oxygen are passed through separate drying towers of soda lime and calcium chloride in the order named, to remove carbon dioxide and water. These towers should be so placed that the gases pass through a minimum amount of rubber tubing before entering the combustion tube, to prevent the absorption of water from the tubing. The introduction of a wash bottle or bubble counter, filled with concentrated sulphuric acid, before the drying towers will remove most of the water and facilitate the detection of leaks (see below).

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* For a complete discussion of modifications of this method and full literature references, see Fisher's "Laboratory Manual of Organic Chemistry" (John Wiley & Sons, Inc., New York).

The combustion tube of clean, dry, hard glass should be about 15 mm. in diameter and 95 cm. long. It should project from each end of the furnace far enough (about 5 cm.) to prevent the rubber stoppers in each end of the tube from getting too hot. This danger can be lessened by the use of a shield of asbestos board at each end of the furnace, or, if necessary, by turning down the burners somewhat at each end. The tube should not project too far from the lower end of the furnace, or water will condense in the end. The filling of the tube is indicated in Fig. 34. Since furnaces vary in length (from 80 to 90 cm.), the dimensions are given only from the two ends of the furnace. The total length of the copper oxide section may vary to fit the furnace. It is filled with coarse, freshly ignited copper oxide which is tightly packed and held in place by tight-fitting copper gauze spirals about 3 cm. in length. The gauze spirals should be fitted with a wire loop, so that they may be withdrawn from the tube by means of a hook. They should be ignited before being placed in the tube. The free space at the upper end of the furnace is used for the boat containing the sample, and the boat is placed far enough from the end to allow the placing of a carefully fitted 10-centimeter gauze spiral inside the tube and within the range of the burners. In the operation of the furnace this spiral is heated before the sample is heated, so that any vapor that diffuses in that direction may be decomposed and not condensed in the cold end of the tube.

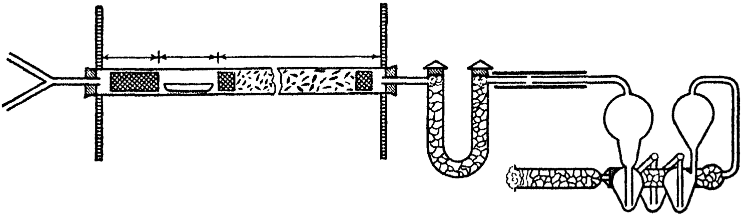

FIG. 34. Combustion apparatus

The calcium chloride U tube should be at least 10 cm. deep, and after it is filled with fine granular calcium chloride it should be sealed off.* When not in use the side arms should be kept closed by rubber dams. Since calcium chloride often contains some free lime, it is necessary to saturate it with carbon dioxide before using it. This is done by passing a slow stream of dry carbon dioxide through the tube for fifteen minutes, putting on the dams, and allowing it to stand for at least an hour, then sweeping out the carbon dioxide with a stream of clean, dry air. A single filling of the calcium chloride tube suffices for many combustions, and it is not necessary to refill it until the top layer of the calcium chloride becomes fully hydrated. Slightly moist calcium chloride absorbs water much faster than does the dry salt. The life of the tube may be lengthened by removing the water which collects in the small bulb of the side arm, or, if no bulb is present, by placing a small wad of cotton above the calcium chloride to catch the condensed water. Cotton wads serve to hold the calcium chloride in place and to catch any dust which might otherwise be carried over into the potash bulbs. If water condenses in the cotton wad nearest the furnace, it should be changed from time to time. Instead of calcium chloride, the U tube may be filled with glass beads covered with concentrated sulphuric acid. In this case the air or oxygen used must be dried initially with concentrated sulphuric acid.

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* It is permissible to close the ends of the U tube with corks placed flush with the ends and carefully covered with thin layers of sealing wax.

The potash bulb may be of any convenient design, but as the speed with which the combustion can be carried out depends largely upon the efficiency with which the water and carbon dioxide are absorbed, some special design is desirable. The ordinary Geissler bulbs combine the advantages of compactness, lightness, and efficiency, but there are other forms just as suitable as this. A solution containing 40 per cent potassium hydroxide is used, and a single filling of the Geissler bulbs will serve for two combustions. A small calcium chloride tube follows the potash absorbent, to stop spray and water vapor. Sodium hydroxide cannot be used in place of the potassium hydroxide on account of the precipitation of the more insoluble sodium carbonate. When not in use, the potash bulbs should be kept closed by rubber dams. It is important that the air or oxygen enter and leave the potash absorbent at the same relative humidity, as otherwise water will be condensed in or evaporated from the absorbent.

Weighing of absorption bulbs. After filling the absorption apparatus, the outside is washed, if necessary, and carefully dried with a cloth, but without rubbing, as the glass might become electrostatically charged. The U tube and bulbs are then suspended from a glass rod by fine wire, and never touched by the hands afterward. Two other effects may interfere with accuracy in weighing, namely, adsorption of water on the glass and having the glass different in temperature from the air in the balance case. The latter is the more important and may be obviated by leaving the glassware in the balance room from one half to three quarters of an hour before weighing. Adsorption of water on the glass will remain nearly constant for any one laboratory period. If desired, a counterpoise of a similar piece of glass apparatus may be used to balance the effect of adsorption. During the weighing, the rubber dams are removed.

Assembling and testing the apparatus. The combustion tube is protected from the metal trough of the furnace by sheets of asbestos which are of the same width as the trough. One-hole rubber stoppers, which have previously been cleaned by boiling in dilute potassium hydroxide for a few minutes, washed with hot water, and dried at 100°, are fitted in the ends of the tube so as to prevent the possibility of leakage and to allow some movement of the tube without working loose. The side arm of the calcium chloride tube is inserted through the lower stopper of the combustion tube so as to be flush with the inner surface. This stopper should fit tightly so that no water may condense between it and the tube during a combustion. A T tube is fitted into the stopper at the upper end of the tube, and this in turn is connected by short pieces of rubber tubing to the drying trains for the air and oxygen. An ordinary calcium chloride tube is filled, half with calcium chloride and half with soda lime, and fitted with a cork so that it may be attached to the combustion tube when the absorption bulbs are not attached. One end of the combustion tube should always be corked tightly and the other protected by this tube when cooling and when not in use.

To prevent the absorption of moisture and carbon dioxide by the potash bulbs from the outside air during a combustion this same calcium chloride tube, or a similar one, should be attached to the small calcium chloride tube which accompanies these bulbs. Then, if the flow of oxygen or air should cease, moist air will not diffuse into the absorption bulbs.

In connecting the absorption bulbs to the tube one side arm of the calcium chloride tube is inserted in the rubber stopper, as directed above, and the other is connected by means of a short black rubber tube to the potash bulbs. The ends of the glass tubing inside the rubber tubing should touch each other. Test the system for leaks by stopping off the end of the potash bulbs, with the tube cold, and start the air. If there is no leak, there will be no passage of air through the apparatus. This is best detected by observing the bubbler filled with sulphuric acid.

When starting with a new combustion tube, or one whose immediate history is not known, place the filled tube in the furnace, start a slow current of air through it, and heat it, gently at first to prevent cracking, and finally to a dull red heat. When no more moisture appears at the lower end of the tube, start oxygen flowing through it slowly instead of air, attach the protective calcium chloride tube, and continue until, at the end of the calcium chloride tube, a test for oxygen is obtained with a glowing splinter. Then connect the absorption bulbs as directed above and regulate the flow of oxygen to about three bubbles per second. When a test for oxygen is again obtained, change to air at the same rate of flow and note the time required to sweep out the tube with air. During this trial note also whether the combustion tube about the stoppers becomes warm. It is just as well to allow the lower stopper to reach 50° or 70° after a combustion is started, to prevent deposition of moisture, and this may be achieved by sliding out the asbestos pad toward the stopper. But it should be certain that the stopper can easily be kept cool if desired, and there never should be any sticking of the stopper to the combustion tube through overheating.

When the oxygen has been swept out by air, the absorption bulbs are disconnected, protected from the atmosphere by rubber dams, and placed in the weighing room. The protective calcium chloride tube is connected with the combustion tube, and the burners under the upper two thirds of the furnace are turned out. While the absorption tubes are cooling, a porcelain boat is ignited and placed in a desiccator to cool. After twenty minutes, weigh the absorption bulbs, allow ten minutes more to elapse, and weigh again. Repeat until two consecutive weighings do not differ by more than 0.4 mg. Attach the absorption bulbs again to the combustion tube, pass air through the system for ten minutes, and weigh again as before. This weighing should not differ from the last by more than 0.4 mg. Repeat the procedure as often as necessary to make sure that no error is introduced into the determination from the construction or manipulation of the apparatus.

Determination of carbon and hydrogen. Considerable time may be saved in making a combustion by noting the points in the procedure that require time. One of these is the weighing; another is the heating of the furnace. On the completion of the testing, the lower part of the furnace should be red hot, and the upper part, where the boat lies, not even warm to the touch. A 0.15–0.20-gram sample, weighed out in the porcelain boat while the absorption bulbs are standing in the weighing room, is inserted in the combustion tube. The absorption bulbs are attached, all the burners except those within 10 cm. on either side of the boat are lighted, and a slow stream of oxygen is started. In handling the gauze spiral at the upper end of the furnace, care should be taken to prevent its coming into contact with any organic matter.

The heating of the furnace must be regulated according to the nature of the substance to be burned. A very volatile substance must be heated very slowly, and this may be accomplished by simply closing over the tiles of the furnace and heating that portion of the tube by conduction instead of lighting the burners under the boat. When the substance is volatilized, any charred material may be burned off by raising the temperature and passing oxygen through the tube. It should be noted that very little danger of incomplete combustion exists if the lower part of the furnace is hot before the boat is inserted or allowed to become warm. As mentioned above, the efficiency of the absorbers determines the rate at which the gases should flow through them, which in turn determines the speed of the combustion. It may be assumed that, with a long combustion tube filled with copper oxide and properly heated, the combustion is complete even though a very rapid stream of gas results from too rapid heating of a volatile substance, but the absorbers may not be able to remove the water and carbon dioxide from such a rapid stream.

The use of oxygen from the beginning of the combustion offers some insurance against incomplete combustion, but there is always danger of explosion if the sample is volatile, especially if the lower end of the furnace is not hot before the sample is admitted to the furnace. Oxygen is necessary to burn off charred material from the boat. A slight discoloration of the boat may be disregarded in estimating the completeness of the combustion, and as soon as the boat appears clean after reaching incandescence, the air flow may be started to replace the oxygen in the apparatus.

Very often a combustion is unduly prolonged by the collection of water in the lower part of the tube, as considerable time is required to remove it. It is advisable to watch this portion of the tube as the combustion proceeds, and at the first sign of clouding, due to condensed moisture, to warm the tube by means of a hot tile and adjust the asbestos pad so as to keep it warm. To complete the determination, pass air through the system long enough to sweep out the tube completely after all the visible moisture and charred material have disappeared, and then disconnect the absorption vessels and weigh them.

By proceeding immediately with a duplicate determination considerable time may be saved. In this case extinguish the burners under the upper half of the furnace only, permitting the lower half to remain at a dull red heat. Remove the boat from the furnace, and while the upper part of the furnace is cooling make the weighings necessary for the next combustion.

Calculation of results. The actual weights of carbon and hydrogen in the sample are calculated from the weights of the carbon dioxide and water respectively. These weights, divided by the weight of the sample and multiplied by 100, give the per cent by weight of carbon and hydrogen. Successive determinations should agree within the error introduced in the weighings, which should be estimated.

THE DETERMINATION OF NITROGEN

Dumas's method. The determination of nitrogen by Dumas's method depends upon the complete combustion of the sample in an atmosphere of carbon dioxide. The products formed are carbon dioxide, water, and nitrogen or oxides of nitrogen. The oxidizing agent used is copper oxide or lead dichromate. A stream of pure carbon dioxide is used to remove air and to sweep the oxidation products through the combustion tube. The oxides of nitrogen are reduced to nitrogen by a gauze of metallic copper. The mixture of carbon dioxide, water vapor, and nitrogen is passed into a nitrometer containing a concentrated solution of potassium hydroxide, where all the carbon dioxide and some of the water vapor are absorbed. Then the volume of the nitrogen is measured. The partial pressures of oxygen and carbon monoxide in equilibrium with copper, copper oxide, and an atmospheric pressure of carbon dioxide at the temperatures involved are too slight to introduce an error in the measured volume of nitrogen.

Preparation of the combustion tube and materials. In the type of combustion tube previously used for the determination of carbon and hydrogen (Fig. 34) enough copper oxide is removed at the lower end of the furnace to make room for a 15-centimeter reduced copper spiral. The remaining coarse copper oxide in the center section is tightly packed and is held in place by tightly fitting gauze spirals prepared as described under the combustion for carbon and hydrogen. The 10-centimeter space occupied by the boat in the previous combustion is loosely filled with fine copper oxide,* which in turn is held in place by an oxidized copper spiral. The tube, filled as above but without the reduced spiral, is placed in the furnace and burned out by passing a slow stream of oxygen through it while it is kept at red heat for at least half an hour. While this ignition is under way the carbon dioxide generator and nitrometer are prepared as described below. When the ignition with oxygen is completed, the carbon dioxide generator and nitrometer are connected to the upper and lower ends of the tube respectively, and carbon dioxide is passed through the red-hot tube until gas no longer collects in the nitrometer. The nitrometer is then replaced by a calcium chloride tube, the burners are turned off, and the tube is allowed to cool with a slow stream of carbon dioxide passing through it. It is important that no air come in contact with the hot copper oxide. This procedure insures the absence of all combustible material from the tube and the displacement from the walls and from the coarse copper oxide of most of the adsorbed air. In filling the tube for the combustion as described below, some air is unavoidably admitted to the tube, but the adsorption of air on the walls is not very rapid, so that unless considerable time elapses between filling the tube and using it, it will be found that the air can be rapidly displaced again by carbon dioxide.

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* This fine copper oxide is removed later, mixed with the sample to be analyzed, and returned to the tube.

Assembly of the apparatus. The carbon dioxide generator consists of a pyrex glass tube 15 mm. in diameter and 30 cm. long, sealed at one end, fitted with a one-hole rubber stopper at the other end, and loaded loosely with pure sodium bicarbonate. Between this and the upper end of the combustion tube a small U-tube trap is inserted to condense and retain water. Short sections of rubber and glass tubing may be used for connections. The generator tube should be inclined to prevent water from running back on the heated portion.

At the lower end of the furnace, connection is made to a nitrometer filled with a 40 per cent solution of potassium hydroxide. A convenient form of nitrometer is shown in Fig. 32, p. 218. If the space below the stopcock has been calibrated, the volume of gas collected can be measured in the nitrometer. If it has not been calibrated, provision should be made to transfer the gas to a eudiometer for measurement (consult instructor). A correction must be made for the vapor pressure of water over the potash solution.

A reduced spiral is prepared by heating a roll of copper gauze about 15 cm. long to a red heat in a large gas flame and plunging it into a deep test tube, at the bottom of which is about 5 cc. of methyl alcohol. A stopper is inserted loosely, and, if no pressure develops, it is pressed tightly into place to prevent the ingress of air as the tube cools. After the spiral has cooled, a length of 3 cm. at one end of it is reoxidized by heating it in an oxidizing flame. The oxidized end of the spiral is placed toward the end of the furnace. This is done because in impure copper screening, which is often used, the metallic impurities reduce small amounts of carbon dioxide to carbon monoxide, which then appears with the nitrogen. The oxidized end of the spiral will reoxidize the carbon monoxide. The reduced spiral will not oxidize rapidly in the air at room temperature.

Since the combustion is to be carried out in an atmosphere of carbon dioxide, and all the oxygen for the combustion must come from the copper oxide, the finely ground sample to be analyzed is intimately mixed with the fine copper oxide which has been ignited in oxygen and carbon dioxide (see footnote, p. 274). The sample is weighed out in a 50-cubic-centimeter glass-stoppered weighing bottle. About two thirds of the fine copper oxide to be used is added and the mixture is shaken thoroughly. The mixture is then poured into the combustion tube with the aid of a dry funnel; care should be taken that none of it sifts past the first copper spiral. The fine copper oxide must not be packed tightly in the tube. A channel is left along the top to allow the passage of a stream of carbon dioxide. The weighing bottle is washed out with the remaining copper oxide, which is added to the combustion tube. The oxidized spiral used in the combustion for carbon and hydrogen is inserted to keep the fine copper oxide in place, the reduced spiral is then put in position, and the tube is placed in the cold furnace. The carbon dioxide generator and nitrometer are connected, and while still at room temperature the system is tested for leaks by first raising the nitrometer leveling bulb to fill the nitrometer with the potash solution,* and then lowering it until air from the combustion tube passes through the side arm and rises into the potash solution. If the leveling bulb is held at a constant level, the bubbles of air will cease unless there is a leak in the apparatus. When it has been demonstrated that there are no leaks in the system, lower the level of the potash solution in the nitrometer by opening the stopcock slowly. If it is opened too rapidly, the solution may be forced past the mercury in the side arm. The leveling bulb is normally maintained at a level near that of the side arm and below that of the combustion tube, to avoid excessive gas pressure in the apparatus and to minimize the danger of the potash solution's rising into the combustion tube.

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* In raising the bulb take care that the liquid does not rise past the mercury in the side arm leading to the combustion tube. The rubber tube connecting the side arm with the combustion tube may be pinched off to stop this. The pinch clamp must be removed after the bulb is lowered.

The combustion. A small flame is applied at the sealed end of the carbon dioxide generator, and the displaced air is allowed to escape from the nitrometer without passing through much of the potassium hydroxide solution. From time to time the issuing gases are tested for air by raising the potash solution in the nitrometer while the carbon dioxide stream is continued until, on two minutes' slow bubbling, no visible volume of air collects in the nitrometer. The removal of air can be hastened by rotating the generator and combustion tube from time to time, to shake up the contents.

While the air is being removed, the burners are lighted under the reduced spiral and a part of the coarse copper oxide. When this part of the furnace has reached incandescence, the nitrometer is completely filled with the potassium hydroxide and the air displacement is tested, as described in the last paragraph. When the air has been satisfactorily removed, the combustion of the sample may be started. At this stage the nitrometer is full of potash solution and the leveling bulb is in a lowered position. The burners are lighted on both sides of the fine copper oxide but not under it, and the rate of heating of the sample is controlled by the nearness of the flames and the positions of the tiles which cover the tube. As soon as gas starts to appear in the nitrometer the tiles in the neighborhood of the sample should be laid back and the tube cooled until the rate of evolution of nitrogen decreases. When this occurs the tiles may be replaced and the burners under the sample lighted, one by one, to maintain a slow, even flow of nitrogen. At no time should the bubbles appear so rapidly that they cannot be readily counted. If they do, the portion of the tube containing the sample should be cooled down by putting out the burner which was last lighted and by opening the tiles. Eventually this section of the tube is heated to dull redness.

The nitrogen is driven over into the nitrometer by a slow stream of carbon dioxide.* The completion of this can be ascertained by watching the size of the bubbles rising through the potash solution and by noting that the volume of the gas no longer increases. The rate of flow of the carbon dioxide may be high at the beginning but must be slowed up during the testing for air, and may again be increased when the combustion is finished. When all the nitrogen has been swept out of the tube, disconnect the nitrometer before allowing the furnace to cool.† Remove the nitrometer from the combustion room to the balance room. The nitrogen should remain in the nitrometer for at least an hour to insure the complete absorption of carbon dioxide. If a calibrated nitrometer is used, the gas volume is measured in it; if not, the gas is transferred to a eudiometer over water and brought to a constant known temperature, and the volume is read. The barometer reading and the temperature are taken at the time the volume is measured.

One of the largest sources of error in the determination is due to the occlusion of air or nitrogen in the copper oxide. The occluded gases are slowly driven out on heating. The preliminary heating of the tube in a stream of carbon dioxide usually eliminates this difficulty. Incomplete combustion, giving rise to carbon monoxide, which is not absorbed by alkali, may give high results. Another source of carbon monoxide is the action of carbon dioxide upon impurities in the copper gauze. This may be corrected as suggested above or by using a pure copper gauze. In any event it is not wise to heat the reduced spiral to a temperature above a dull red heat.

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* The flow of carbon dioxide must not cease entirely, but it may become slow while the sample is being heated. If it becomes too slow, both the potassium hydroxide in the nitrometer side arm and the sodium carbonate in the generator may absorb the gas faster than it is being produced, and draw the potash solution into the combustion tube.

† If another determination is to be made, remove the reduced spiral and pass oxygen and carbon dioxide successively through the hot furnace as described above under "Preparation of the combustion tube."

Calculation of results. The gas as finally measured is saturated with water vapor either from the potash solution or from pure water, so that if it is desired to calculate the weight of nitrogen from the gas law,* $PV = nRT$, the vapor pressure of the water at the observed temperature must be subtracted from the barometric reading to obtain the actual pressure of the nitrogen. The accuracy of this application of the gas law is within the experimental error. A table in the Appendix gives the vapor pressures of some potassium hydroxide solutions. Two successive determinations should agree within 2 per cent of the calculated percentage of nitrogen.

THE DETERMINATION OF CARBON AND HYDROGEN IN THE PRESENCE OF NITROGEN, SULPHUR, HALOGENS, AND ALKALI METALS †

In the presence of *nitrogen* the sample is mixed with fine copper oxide and the combustion tube is filled as in the determination of nitrogen. The reduced spiral is not placed in the combustion tube until everything else is ready. The combustion is carried out as in the determination of carbon and hydrogen by Liebig's method, described above, except that no air or oxygen is passed until the tube and sample are red hot. The carbon dioxide and water are then swept out with air or oxygen, or with both. This procedure prevents the reduced spiral from becoming oxidized until very nearly all the products of combustion have been swept out of the tube. When it is seen that the oxidation of the reduced spiral has begun, shut off the burners under it to prevent complete oxidation. Oxides of nitrogen may be removed also by lead peroxide (see page 280).

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* When P is given in atmospheres, V in cubic centimeters, and T in degrees absolute, the gas constant R has the value 82.1. The factor n is the number of mols of gas ($m/28$ in this case), where m is the mass of nitrogen. This equation is equivalent to the statement that one mol of gas under standard conditions occupies 22.4 liters, coupled with Boyle's law and Charles's law.

† Dennstedt, Anleitung zur vereinfachten Elementaranalyse, 3 Aufl. (1910); *Ber.*, **41**, 600, 2778 (1908); Bekh, *Ber.*, **46**, 2574 (1913); Reimer, *J. Am. Chem. Soc.*, **37**, 1636 (1915); Levene and Bieber, *J. Am. Chem. Soc.*, **40**, 460 (1918); Kingscott and Knight, Methods of Quantitative Organic Analysis (1914).

In the presence of *sulphur* or *halogens* it is better to mix the sample with fine, dry lead chromate. The lead chromate should be heated in a stream of oxygen, dried thoroughly in an oven at 120°, and cooled in a desiccator just before using, since it is very hydroscopic. It should not be heated to as high a temperature as is used with copper oxide, for it fuses and sticks to the glass. Coarse, glassy particles should be sifted out. An alternative method is to prepare a 6-centimeter cartridge of lead chromate and insert this in the upper end of the combustion tube, just below the sample, in place of some of the coarse copper oxide. This cartridge is made by filling a cylinder of copper gauze, which fits the combustion tube, with granular lead chromate. The sample is then mixed with fine copper oxide as before, and the chromate cartridge is heated before the sample is allowed to volatilize.

The lead sulphate formed does not decompose nor volatilize, but this is not true of lead halides. It is necessary in the presence of a high percentage of halogens to insert in the extreme lower end of the tube a boat of reduced silver powder or a 5-centimeter roll of silver foil, to absorb the halogens. The silver should not be heated too strongly (500°–600°), and the combustion should be carried out more slowly than in previous determinations. When the silver foil becomes covered with halide, it may be reduced in a stream of hydrogen and the occluded hydrogen may be burned out in a nonluminous flame.

When only a small percentage of halogen is present, the silver foil may be omitted. The lead-chromate cartridge alone will retain the halogen in that case. The copper oxide used in the presence of halogen should be kept separate and should not be mixed with copper oxide which is known to be free from halides.

Oxides of nitrogen and sulphur are completely absorbed by a mixture of lead peroxide and red lead at 300°–320°. The halogens also are absorbed, but incompletely. The reduced copper spiral for the reduction of oxides of nitrogen may be replaced by boats containing this mixture, or by asbestos covered with it, or by a gauze cartridge filled with it. Approximately 10 cm. of the tube should be filled with the absorbent. It must be placed below the copper oxide, as all the organic matter must be completely oxidized before reaching it. This absorbent must be handled with greater care than the reduced spiral or lead chromate, but it is very useful for the absorption of the oxides of nitrogen and sulphur in the combustion of substances containing these elements.

If an alkali metal or barium is present, the substance should be mixed with carefully dried lead chromate in the boat, to prevent the retention of carbon as the carbonate of the metal.

THE DETERMINATION OF HALOGENS

The Carius method.* This method depends upon the complete oxidation of the compound by fuming nitric acid in the presence of silver nitrate. The silver halide formed is weighed as usual on an asbestos filter.

The weight of the sample to be used depends upon the percentage and nature of the halide present. Enough should be used to give from 0.2 to 0.4 g. of silver halide. The sample is weighed in an open tube of about 5-millimeter diameter.

The reaction is carried out in a clean, dry, thick-walled bomb tube at least 10 mm. in diameter and 40 cm. long when sealed. The amount of fuming nitric acid used should be as small as possible but sufficient to insure oxidation, — usually about ten times the weight of the sample. A large sample and an excess of nitric acid tend to increase the pressure in the bomb tube, leading to explosion.

Procedure. With the aid of a long-stem funnel the acid is placed in the bottom of the bomb without wetting the sides. Excess of solid silver nitrate is added (0.5 to 1 g.), and the tube containing the sample is then lowered into the bomb tube. Care is exercised to avoid mixing the acid and the sample. The bomb is then constricted, drawn to a thick-walled capillary, carefully annealed, and sealed (Fig. 35). The constriction may be made close to the end of the tube if another glass tube is first sealed to the bomb to serve as a handle, as shown in the figure.

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* Gattermann, Practical Methods of Organic Chemistry; Houben-Weyl, Die Methoden der organischen Chemie.

As soon as the seal is cold, the tube is placed in an iron casing provided for that purpose. It is sometimes advisable to wrap the bomb in a thin sheet of asbestos to protect it from scratches. The asbestos is tied with copper wire. The end of the wire should extend to the mouth of the casing, so that the bomb can be drawn out without at any time tipping it in such a way that particles of the silver precipitate are washed into or near the capillary. The iron casing, with cap in place, is then inserted in the cold bomb furnace, care being taken to maintain the capillary end of the bomb at a higher level than the other.

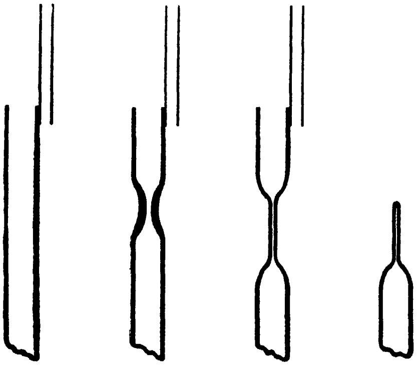

FIG. 35

The furnace is heated slowly (about 100° an hour) to 300°, and maintained at 300°–350° for two hours or longer to insure complete decomposition. The bomb is allowed to cool in the furnace, and *under no circumstances should it be taken from the iron casing until quite cold, and then only as follows*: Remove the cap and, standing out of line with the casing, draw out the bomb by means of the copper wire until the capillary protrudes from the casing. It is advisable to wear goggles and wrap the hands in towels while doing this. Heat the capillary gently to drive out any liquid, and then heat it strongly with a small flame until it blows out. The bomb is then safe for handling.

Complete combustion is evidenced by a clear brown or blue solution, which loses its color if warmed on the water bath, and by the absence of charred material or oil drops. In case of doubt the capillary should be resealed and the tube reheated with or without the addition of more nitric acid.

To open the tube a file scratch is made at the base of the capillary and the capillary is broken off. The broken end of the bomb is now heated in the flame until the glass softens. The point of a clean file is then inserted in the small opening, and the opening is enlarged. Alternate heating and working with the file point will produce a large opening without danger of glass particles' falling into the bomb.* Wash the contents of the bomb into a beaker and boil the mixture thoroughly. Consult any standard textbook of quantitative analysis with reference to handling the precipitate.

Long heating of the bomb and large samples lead to explosions. It is sometimes necessary to cool after the temperature has reached 200°, open the bomb to release the products of combustion (observing the precautions above), reseal, and continue heating.

Duplicate determinations should be made, and the results should agree within the limits of the ordinary gravimetric process.

The results, calculated from the known composition of the silver halide, the weight of the silver halide, and the weight of the sample, are expressed in terms of the weight per cent of halogen in the sample.

THE DETERMINATION OF SULPHUR

The Carius method. This determination is carried out precisely as is the determination of halogens, except that silver nitrate is omitted from the charge of the tube. The oxidation results in the production of sulphuric acid, which is determined as barium sulphate in the usual way. The weight of sample depends on the amount of sulphur present and the amount of precipitate of barium sulphate which it is convenient to handle. The same precautions are taken in charging, heating, and opening the bomb, particular care being taken that no loss of liquid occurs on opening. The percentage by weight of sulphur in the sample is calculated from the weight of barium sulphate obtained.

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* If there is any suspicion that the precipitate contains glass, proceed to weigh the precipitate on a washed asbestos Gooch filter as usual. Then dissolve out the precipitate with 6 *N* ammonia or potassium cyanide solution, wash the filter thoroughly, dry, and reweigh. If glass is present, this final weight will be greater than the original tare weight and may be used to correct the weighings.

THE DETERMINATION OF NITROGEN

The Kjeldahl method. This process depends upon the conversion of nitrogen to ammonia, the distillation of this into a standard acid solution, and the determination of the ammonia by titration.

Digestion. Enough of the sample is used to give ammonia equivalent to about 20 cc. of 0.1 *N* acid. The sample is weighed into the digestion flask (a round-bottomed flask of 500-cubic-centimeter capacity with a long neck). A catalyst is added; then 20–30 cc. of concentrated sulphuric acid is introduced. To raise the boiling point of the acid, about 10 g. of potassium sulphate should be added. The mixture is heated gently until frothing ceases, and is then boiled for at least an hour, or until it becomes colorless or has a very pale yellow color.* If necessary, more acid is added to replace that which distills off. The flask above the level of the acid should be protected from the free flame to prevent volatilization of ammonium sulphate.

Catalyst. The catalyst most commonly used is mercuric oxide (0.7 g.) or metallic mercury (0.5 g.). Anhydrous copper sulphate is sometimes used. If difficulty is experienced in completing the oxidation of the carbon, a *little* solid potassium permanganate is added to the hot mixture at the end of the digestion, immediately after removing the flask from the flame. The permanganate should be slowly added in small quantities until a permanent green or purple color is produced.

If nitrates or nitro bodies are present, add about 1 g. of salicylic acid and allow the mixture to stand for ten minutes after dissolving; then add 5 g. of sodium thiosulphate, heat gently for five minutes, and let the mixture stand overnight. The mercury or mercuric oxide catalyst and the potassium sulphate are then added, and the digestion process is carried out as indicated above. This digestion should proceed for at least six hours. A little zinc dust may be substituted for the sodium thiosulphate.

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* Some nitrogenous ring compounds, such as pyridine and quinoline, are not completely decomposed even after ten hours of heating with the sulphuric acid. Aromatic amines are usually incompletely converted to ammonia in six hours, but consistent results may often be obtained upon eight or ten hours' digestion. In case of doubt, duplicate samples are digested for successively longer periods until samples heated for different lengths of time agree in results. It is often found that if two samples are treated alike, perfect agreement is shown but that both results are greatly in error.

Distillation. After digestion, cool the mixture and carefully add 200 cc. of distilled water. If mercury or mercuric oxide has been used as a catalyst, add 25 cc. of a 4 per cent potassium sulphide solution to precipitate the mercury.

The distillation is carried on through a trap to a condenser, which dips into a known amount of standard acid. When these are in place, carefully pour 12 N sodium hydroxide solution down the side of the flask so that it collects as a layer at the bottom. Enough must be added to render the solution alkaline, but a large excess should be avoided. The quantity required can be calculated from the amount of concentrated sulphuric acid used. Connect the flask to the trap. *Mix the acid and alkali by carefully shaking the flask*; then distill the mixture, collecting 150 cc. of distillate in a measured volume of standard acid solution.

Instead of adding the required quantity of alkali all at once, as indicated above, a small separatory funnel passing through the stopper of the distilling flask by the side of the trap will allow the slow addition of alkali and the use of an indicator to show when the mixture is alkaline. In this case all connections must be in place and *tested for leaks* before the alkali is added. The end of the condenser must dip beneath the surface of the standard acid, and arrangements must be made for the clearance of the end of the condenser in case acid is drawn back.

The amount of acid in the receiver must be in excess of that necessary to neutralize the ammonia. When the distillation is completed, the end of the condenser is washed off and the excess acid is titrated with standard base, methyl red or methyl orange being used as indicator.

Winkler has suggested the use of a 4 per cent boric acid solution in the receiver instead of the standard sulphuric acid; 50 cc. of such a solution will retain about 90 mg. of nitrogen as ammonia. Since the boric acid has little or no effect on the indicator, it need not be measured accurately, and the solution, after distillation, may be titrated directly by standard sulphuric acid. In this case a titration blank should be used, to give the same end point and to correct for any effect of the boric acid.

In all cases the distillation apparatus, the reagents, and the procedure must be tested prior to the actual determination. The apparatus should first be tested for leaks and then cleaned by a preliminary distillation, using water, to remove any traces of volatile acids or bases. The reagents and the procedure are subjected to blank tests, made in duplicate, as follows: Heat the mixture of sulphuric acid, potassium sulphate, and the catalyst to boiling for half an hour. Then proceed with the dilution of the acid, its neutralization, the distillation of the alkaline solution and titration of the distillate, exactly as outlined for the actual analysis. Usually a small but definite amount of base will be detected in the distillate. If this is not greater in amount than that equivalent to 0.2 cc. of 0.1 *N* acid, and is reproducible, it may be used to correct the results of actual determinations.

Except in cases where the conversion of the nitrogen to ammonia is incomplete the accuracy of this method is within the limit of error in the volumetric procedure.

The weight of nitrogen present is calculated from the number of equivalents of ammonia found, and the results are expressed as the percentage by weight of nitrogen.

SPECIAL NOTES ON COMBUSTIONS

The combustion of liquids. The vapor pressure at room temperature of a substance which boils above 170° is very low, so that it may usually be weighed out in an open boat just as a solid substance is weighed. An extra precaution is to weigh the boat in a closed tube before and after the introduction of the sample. A small test tube which has been heated and flattened on one side makes a satisfactory container. To lower the rate of evaporation the boat may be filled with fine freshly ignited and cooled copper oxide as soon as it is taken from the closed container. If the combustion is for carbon and hydrogen, the lower end of the furnace should be hot, and the absorption train should be in place before the boat is placed in the combustion tube. In the combustion for nitrogen, a similar precaution must be observed because a prolonged stream of carbon dioxide will cause more of the liquid to evaporate. In such a case it is necessary to have the boat filled with copper oxide, and before the introduction of the boat to the combustion tube the apparatus is completely assembled except for the oxidized spiral at the upper end of the furnace. The air is almost completely displaced by carbon dioxide, and the lower end of the tube, occupied by the reduced spiral and about half the copper oxide, is ignited to a red heat. The stopper at the upper end of the tube is then removed, the boat and oxidized spiral are quickly put in position, and the stopper is replaced with the introduction of but very little air. This air is rapidly driven into the nitrometer by carbon dioxide, and even though the sample is quite volatile a satisfactory combustion may be made, since it is usually easy to distinguish between the large bubbles of air and the minute bubbles of nitrogen coming from a small concentration of burning vapor.

A liquid which boils without decomposition between 60° and 170° may be placed in a thin-walled bulb blown in a melting-point tube. The capillary end is then sealed off. A tare weight is taken on the bulb before it is filled and sealed. Before being placed in the combustion tube the capillary tube is broken off and the bulb is placed in the boat. The boat is so placed in the combustion tube that the open tip of the capillary tube points toward the lower end of the combustion tube. The same precautions in handling the furnace are taken as above, and if the sample is carefully heated it will volatilize without charring.

Reference may be made to other books * for methods of handling very volatile liquids.

Explosive substances. Compounds that decompose violently on heating may be analyzed by the combustion method if mixed with a large quantity of an inert substance such as dry sand or dry copper oxide.

The use of lead chromate. When a substance which chars readily is to be analyzed for nitrogen, it is often advisable to mix the sample in a boat with lead chromate instead of with copper oxide. Some chemists recommend filling the combustion tube with coarse, dry lead chromate instead of with coarse copper oxide for use in the case of substances that are difficult to burn completely in an atmosphere of carbon dioxide.

Factors governing the rapidity of the analysis. Considerable time (at least half an hour) is required to heat the combustion tube or any part of it to a dull red heat, and the lower part of the tube must reach this temperature before it is safe to *start* heating the sample. Time may therefore be saved in the case of the carbon-hydrogen combustion by having the lower part of the tube hot before the sample is introduced, and in the case of the nitrogen combustion by starting to heat as soon as it is evident that carbon dioxide has reached the nitrometer, which may be some time before the air is completely displaced. An even longer time (one or two hours) may be required for the hot furnace to cool completely. Allowance must be made for this in the planning of the work.

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* References are listed in the footnote on page 267.

The rate of heating of the sample depends upon the capacity of the absorption train to absorb water and carbon dioxide, and upon the catalysis of the combustion by the copper oxide. Cerium dioxide and metallic platinum are better catalysts, if properly used, than is copper oxide; hence their use may permit a more rapid combustion. The rate of absorption of water by different reagents varies with their nature and method of preparation. The use of two U tubes in series, each filled with specially prepared soda lime, will absorb completely a more rapid stream of carbon dioxide than will one set of Geissler bulbs filled with potassium hydroxide solution.

The evaporation of water which has deposited in the cold end of the combustion tube requires a long time. Prevent this deposition by keeping the end of the tube warm, but not hot enough to burn the stopper.

The weight of the water and the weight of the carbon dioxide are each determined by the difference in two weighings. The accuracy depends not only upon the correct weighing of the glassware itself but also upon the presence at the time of each weighing of the same amount of water, grease, etc. adsorbed on the glass. If the piece to be weighed differs much in temperature from the temperature of the air in the balance case, convection currents will interfere with the weighing. Time may therefore be saved by the adoption of a standardized procedure in making the weighings. It may be just as accurate to weigh the absorption train immediately upon its removal from the combustion room as to wait for half an hour, *provided that the same conditions apply for each weighing.* Repeated blanks may satisfy the operator as to the validity of any procedure best suited to his needs.

An error will be introduced if the towers which precede the combustion tube are more efficient in their absorption of water and of carbon dioxide than are the absorption vessels which follow it. This error will be accentuated by too rapid a stream of air or too prolonged a combustion. The blanks, then, should coincide in point of time as well as in materials with the actual determination in order to be an accurate indication of the trustworthiness of the procedure. A blank of ten minutes' duration may offer a test of the weighings alone, whereas one of an hour's duration may be necessary adequately to test the relative efficiency of two sets of absorbents.

Any results should be considered worthless when accompanied by burnt stoppers, the belated detection of leaks, too rapid or too slow combustion, or any other faulty manipulation likely to affect the results. Success is dependent entirely upon adherence to a standardized and tested procedure.

PROBLEMS FOR REVIEW

1. If x is the fraction in equivalents of a salt of a weak acid titrated by a strong acid at any given hydrogen ion concentration C, show that the dissociation constant K_a of the acid contained in the salt is given approximately by the equation

$$K_a = \frac{1 - x}{x} C.$$

2. In testing for a carboxyl group, why cannot an aqueous solution of the substance be tested with blue litmus paper?

3. In titrating a strong acid with a strong base, can either methyl orange or phenolphthalein be used as indicator? What would be the magnitude of the difference in the two end points if 0.1 N alkali were used and the volume at the end point were 200 cc.?

4. How accurately is the equivalent weight of a substance known if a 0.1-gram sample, weighed to 1 mg., is titrated with 0.5 N alkali whose normality is known to within 0.2 per cent? Assume that the equivalent weight is about 200.

5. Why does solubility in alkali of a water-insoluble substance denote acidic properties? Express by an equation the behavior of a phenol when dissolving in alkali.

6. An acidic substance contains water of crystallization, and on heating to drive off the water the acid itself either volatilizes or decomposes. Suggest a method for determining the number of molecules of water of crystallization per equivalent of acid.

7. Why does aniline hydrochloride titrate as an acid with sodium hydroxide if phenolphthalein is used as the indicator?

8. What acid chlorides other than those of phosphorus can be used to prepare carboxylic acid chlorides?

9. In the titration of 0.1 mol of acetic acid ($K_a = 1.9 \times 10^{-5}$) with sodium hydroxide, using methyl orange, the yellow color of the indicator is reached before one half the required amount of alkali has been added; but if phenolphthalein is used, approximately 0.1 mol of the alkali would have to be added to get a change in color. Explain. In the titration with methyl orange the color change is gradual and the end point therefore indefinite. Explain. What would happen as regards sharpness of end point and relative amount of alkali necessary if 0.1 of a mol of a very weak acid ($K_a = 1 \times 10^{-9}$) were titrated with phenolphthalein?

10. What is an acid amide? an anilide? Write structural formulas for propionyl toluide; for malonyl ureid; for glycyl glycine.

11. In each of the following pairs of reactions choose that which proceeds more rapidly at room temperatures:

a. The bromination of phenol with bromine water or the sulphonation of phenol with concentrated sulphuric acid.

b. The condensation of phenol with phthalic anhydride in the presence of concentrated sulphuric acid or the condensation of phenol with phenyldiazohydroxide, $C_6H_5—N{=\!=}N·OH$.

c. The bromination of ether or the bromination of phenol.

d. The neutralization of phenol with dilute sodium hydroxide solution or the esterification of formic acid with methyl alcohol.

12. Write the structural formula of an enol and show by comparison of their formulas why phenols and enols are similar in some respects.

13. What is meant by "steric hindrance" when applied to the hydrolysis of esters? Give examples.

14. If in the hydrolysis of an ester a homogeneous hydrolyzing medium is obtained by the use of alcohol, how can you be sure that hydrolysis is complete?

15. The titration of a carbonate with an acid, using phenolphthalein as an indicator, changes upon heating the solution. Do salts of other acids, such as phenols, boric acid, and carboxylic acids, behave in the same way? Explain.

16. Is it usual or unusual (1) for 1, 3 diketones to produce acids and (2) for beta ketonic esters to produce carbonate when heated with 1 *N* aqueous alkali for an hour?

NOTE. Refer to Beilstein to determine the conditions under which these reactions have been carried out in specific cases.

17. What is meant by a "blank" when hydrolyzing an ester in a sealed tube? Why is a blank necessary?

18. Name four acids which can be distilled from a mixture of their dry salts with sulphuric or phosphoric acids. Why cannot all acids be isolated in that way?

19. What type of acid cannot be extracted by ether from an aqueous solution?

20. Outline a process for preparing an anilide from the salt of an acid.

21. What is a lactone? How can it be distinguished from an ether, an acetal, or a simple ester?

22. Explain why a solution of butyric acid in water gives, on distillation, more acid in the first distillate than does a solution of acetic acid of the same molal strength.

23. State which of the following substances react most rapidly with each of the reagents listed below, at room temperature, with (1) acetaldehyde, (2) benzaldehyde, (3) ethylene, (4) acetone, (5) alcohol:

Bromine water, at room temperature
Alkaline permanganate solution, at room temperature
Fehling's solution, at 100°
Tollen's reagent, at room temperature
Acidified dichromate solution, at 100°

24. Suggest a means of oxidizing a hydroxy aldehyde to a hydroxy acid.

25. Why does heating color Schiff's reagent? In testing for aldehydes, why is a time limit imposed for the reaction with Schiff's reagent?

26. Why is not the aldol condensation or the polymerization reaction used as a characteristic reaction to detect the presence of an aldehyde group?

27. What is an acetal? If tetramethyl-methyl-glucoside were heated with acid, which of the five methoxy groups would be removed first? Why?

28. Do all ketones react readily with hydroxylamine? Why is hydroxylamine hydrochloride used, and not the free base? Which solution contains more of the free base, — a solution of hydroxylamine hydrochloride or a solution of the salt to which sodium acetate has been added?

29. What is hydroxylammonium ion? Oximes are amphoteric. Write the formulas of the two possible ions.

30. After forming an oxime in sodium carbonate solution, why is it necessary to neutralize, but not to acidify, in order to precipitate the oxime?

31. What is meant by the Beckmann rearrangement of oximes?

32. Do carboxylic acids, esters, and amides react with hydroxylamine under the conditions of the test for ketones? Can the oximes of acids be prepared? What evidence is there that a carbonyl group exists at all in acid derivatives?

33. In testing for a ketone with hydroxylamine, why is not the formation of a new substance (new physical properties) a sufficient indication? Why must the new compound in turn be tested for an oxime group?

34. What is a pentose? a hexose? a glucoside?

35. Why do not aldose sugars appear under Test 4a, Test 4b, and Test 4d, Division I?

NOTE. Aldose and ketose sugars respond to Test 4c, Division I.

36. Write the formulas of two hydrazines, besides phenylhydrazine, that could be used to prepare osazones. Name them.

37. To what extent do alcohols ionize as acids? as bases?

38. Why is not the evolution of hydrogen by means of sodium, or the reaction with phosphorus trichloride, useful as a test for an alcoholic hydroxyl group?

39. In general, which alcohols esterify most rapidly, — primary, secondary, or tertiary? What reaction other than esterification often takes place with tertiary alcohols when they are treated with anhydrous esterifying agents? How could you prepare the ester of such an alcohol?

40. Is the formation of a new substance on treatment with acetic anhydride sufficient evidence of the presence of an alcohol? Tell what could be formed on heating the following with acetic anhydride: (1) acetone; (2) butyric acid; (3) benzaldehyde.

41. If absolute alcohol were saturated with dry hydrogen chloride gas at room temperature, would the formation of ethyl chloride be complete after one hour? after one day? Can alcohol be used as a solvent when bromine or potassium permanganate is one of the reagents?

42. Which alcohols are completely miscible with water at room temperature? Which monocarboxylic acids? Which ketones? Are any liquid alcohols sparingly soluble in ether?

43. Write equations to represent the reactions of bromine with the following classes of compounds: (1) a phenol; (2) an enol; (3) a polyhydric alcohol; (4) a ketone.

44. How does bromine react in alkaline solution with ethyl alcohol?

45. In alkaline solution permanganate reacting with various types of ethylenes may give a glycol, a hydroxy acid, two acids, two ketones, or a ketone and an acid. Represent these reactions by balanced equations.

46. What is the Friedel-Crafts reaction?

47. Why is the aluminum chloride sublimed for Test 8a, Division I?

48. What evidence is there that an ether may form oxonium compounds similar to ammonium compounds? Does the oxygen in water and in alcohol have the same tendency? sulphur in sulphides? iodine in iodides?

49. Which salts will decompose at the lower temperature, — oxonium or ammonium? What are the products of decomposition in each case? Why does ether not dissolve in all proportions in concentrated hydrochloric acid as it does in sulphuric acid?

50. What strength of sulphuric acid is used in determining ethylene in gas and oil analysis? Is the original product recovered in this case on adding water? What classes of organic substances are not, in general, soluble in cold concentrated sulphuric acid?

51. Are benzene and naphthalene rapidly sulphonated by concentrated sulphuric acid at room temperature?

52. The ethyl ester of an acid was prepared, and 0.2 g. of it, when heated with an alcoholic solution of sodium hydroxide, neutralized an amount of alkali equivalent to 4.5 cc. of 0.5 *N* hydrochloric acid. What is the equivalent weight of the acid?

53. How could you separate phenol from an aqueous solution of acetic acid?

54. 1.0 g. of a given sample of acetic anhydride used up 21.5 cc. of 1.0 *N* sodium hydroxide. 8.0 g. of this acetic anhydride and 2.0 g. of an unknown were heated together until acetylation was complete. The excess acetic anhydride and acetic acid was found to neutralize 116.5 cc. of 1.0 *N* sodium hydroxide. If the molecular weight of the unknown is 180, how many hydroxyl groups are there in a molecule of the unknown?

55. What differences should you expect between the action of sodium hydroxide on acetamide and on ammonium acetate, with respect to the products formed and the relative rates of the reactions?

56. If in a 1.0 *M* aqueous solution of an amine the OH^- concentration is 1×10^{-4} mols per liter, what is the concentration of H^+ in a 1.0 *M* aqueous solution of the hydrochloride of the same amine?

57. Write the equation for the formation of a quaternary salt by the action of an alkyl halide on a tertiary amine, using the classical structural formula and the electronic formula to represent each substance. What are the advantages of the latter formulation?

58. Represent in two ways, by equations, the production of H^+ in an aqueous solution of the salt and an amine.

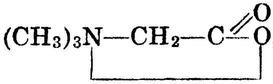
59. Would a quaternary ammonium chloride give an ether-soluble substance on treatment with a cold dilute solution of sodium hydroxide?

60. Name three types of substances containing nitrogen which show acidic properties, and three others which show basic properties.

61. Would more or fewer substances show basic properties if methyl violet were substituted for Congo red in Test 2, Division II?

62. Explain why it may be more accurate, in determining the equivalent weight of benzidine, to prepare the pure dihydrochloride and titrate a sample with alkali, using phenolphthalein, than to titrate a solution of the base directly with acid, using methyl orange.

63. Place the following substances in the order of the OH^- concentrations which would be given by solutions of equivalent molality: ammonia, aniline, methylamine, dimethylamine, diphenylamine, phenyl trimethyl ammonium hydroxide, phenylhydrazine, sodium acetate, urea, acetanilide.



64. Why is betaine, $(CH_3)_3N{-}CH_2{-}C\overset{\displaystyle O}{\diagup\!\!\diagup}\!{-}O$, a basic substance?

NOTE. Betaine is not a sufficiently strong base to give Test 2, Division II, but it does form a salt with hydrogen chloride.

65. Write an equation to represent the solution of a water-insoluble amine in dilute acid. Express in words the reasoning by which it is concluded that if a substance is sparingly soluble in water but soluble in acid, it has basic properties.

66. If a base such as β-naphthylamine is precipitated from a solution of its hydrochloride by the addition of ammonia, does that prove that ammonia is a stronger base than β-naphthylamine?

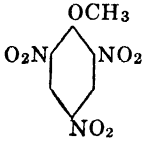
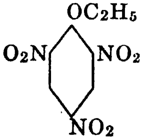
67. Explain the results of the following experiment: Diphenylamine is more soluble in 6 *N* hydrochloric acid than in water. If to a saturated solution of diphenylamine in 6 *N* hydrochloric acid an equal volume of water is added, a precipitate appears.

68. Explain why nitrophenols change color when treated with alkalies.

69. Explain how $C_6H_5CH_2NO_2$ forms a salt with sodium hydroxide, and why the neutralization of sodium hydroxide by $C_6H_5CH_2NO_2$ is slower than its neutralization by ordinary acids.

70. Devise a test which would distinguish aromatic from aliphatic nitro compounds.

71. How does sodium hydroxide form a salt with trinitrobenzene?

NOTE.  and $NaOC_2H_5$ combine to form the same product as is formed by the combination of  and $NaOCH_3$.

72. Given that hydroxylamine is a stronger base than is an oxime, prove that the equilibrium

$$R_2C{=}NOH + H_2O \rightleftarrows R_2CO + NH_2OH$$

is shifted so as to favor the formation of the ketone if the hydrochlorides of the oxime and of hydroxylamine are substituted for the free bases.

73. How may an aldose sugar be changed to a ketose sugar through the formation of an osazone? How are the osazones used to compare the stereo structures of the isomeric aldoses?

74. What is a hydroxamic acid?

75. With what class of substances are the oximes isomeric? Are they stable or unstable with respect to this isomeric class of compounds?

76. Why are oximes sometimes termed isonitroso compounds? What is the character of the change from the one type of compound to the other? Which type is stable with respect to the other? Point out a similar relationship between azo compounds and hydrazones. Of this pair which is the more stable?

77. Write equations for all the reactions involved in Test 5d, Division II.

78. Explain why diazotization of an aromatic primary amine is best carried out in excess of strong acid.

79. Calculate the equivalent weight of an amine if 1.0 g., when heated with nitrous acid, gives 40 cc. of nitrogen gas measured at 20° C. and 765 mm. of Hg.

80. Write equations for the action of a mixture of sodium nitrite and hydrochloric acid upon methylaniline and dimethylaniline respectively.

81. How may nitrous acid be used to obtain methylaniline from a mixture of aniline, methylaniline, and dimethylaniline?

82. Explain the theory of the separation of primary, secondary, and tertiary amines with benzenesulphonyl chloride. Could acetyl chloride be used instead of benzenesulphonyl chloride? Explain.

83. State which of the following substances you would expect to react (1) with a tertiary amine and (2) with a secondary amine:

Benzoyl chloride
Methyl iodide
Sulphuric acid
Phenol
Phenyl chloride

84. What is the "mustard oil" reaction of primary aliphatic amines? Is it given by primary aromatic amines?

85. The diazohydroxides are ampholytes. They react with either hydrogen or hydroxide ion. Represent the two reactions by balanced equations.

86. Tell which of the following ions, when united with the phenyldiazo ion, $C_6H_5—N_2^+$, forms the most dissociated compounds and which the least dissociated compound: (1) hydroxide ion, OH^-; (2) phenylamide ion, $C_6H_5NH^-$; (3) chloride ion, Cl^-; (4) cyanide ion, CN^-; (5) phenolate ion, $C_6H_5O^-$. Which two of the possible compounds tend to rearrange rapidly into the more stable compounds $C_6H_5—N{=}N—C_6H_4NH_2$ and $C_6H_5—N{=}N—C_6H_4OH$? Could these also be considered as stable un-ionized compounds of the diazo ion and of $C_6H_4NH_2^-$ and $C_6H_4OH^-$ ions respectively? The decomposition of an aliphatic azo compound,

$$CH_3—N{=}N—CH_3 \longrightarrow C_2H_6 + N_2,$$

is typical of all diazo derivatives. Give two other examples of this decomposition from among the aromatic diazo compounds.

87. Devise formulas for *p*-nitrosodimethylaniline and for the positive ion of its hydrochloride which might account for the difference between the color of the base and that of its salt.

88. Both amides and amidines yield acids and ammonia or amines on hydrolysis. How could you distinguish between these two classes of compounds by a study of their hydrolyses?

89. Some amides yield imido chlorides on treatment with phosphorus pentachloride; some yield nitriles on the same treatment. What type of amide permits the isolation of the imido chloride?

90. How could you distinguish between a nitrile and an isonitrile from an examination of the products of hydrolysis?

91. Starting with $C_6H_5SO_3Na$, how could you prepare phenylbenzenesulphonamide, $C_6H_5SO_2NHC_6H_5$?

92. How could ethyl sulphonic acid be prepared?

93. How could you distinguish a mercaptan from a thioether?

94. What are sulphones? sulphonic acids? sulphinic acids?

95. Which hydrolyzes the more rapidly, — ethyl chloride or ethyl iodide?

96. Which reacts the more rapidly with trimethylamine, — $CH_2Cl—CO_2C_2H_5$ or C_2H_5Cl?

97. Which hydrolyzes the more rapidly, — C_6H_5I or C_2H_5I?

98. State which of the following reactions is the more rapid and which is the more complete:

$$C_6H_5COCl + H_2O \longrightarrow C_6H_5COOH + HCl,$$
$$CH_3—CH_2—CH_2Cl + H_2O \longrightarrow CH_3—CH_2—CH_2OH + HCl.$$

99. A substance containing only carbon, hydrogen, and oxygen can be accurately titrated with sodium hydroxide, with phenolphthalein as the indicator. 0.1 g. of the substance requires 19.6 cc. of 0.1 *N* sodium hydroxide in this titration. From the reaction product a sodium salt can be obtained which in the anhydrous condition contains 28.05 per cent of sodium. Write a formula for a substance which would account for these results.

100. A substance which contains only carbon, hydrogen, and chlorine, on analysis by the Carius method gives 44.1 per cent chlorine. When boiled with alcoholic sodium hydroxide it formed chloride ion corresponding to 22.05 per cent of the original substance. The substance when warmed with aluminum chloride readily forms hydrogen chloride. Write a formula which would account for these results.

101. A substance which contains carbon, hydrogen, oxygen, and nitrogen is almost neutral when titrated with acids or alkalies if the end points are taken at $(H^+) = 1 \times 10^{-2}$ and $(H^+) = 1 \times 10^{-11}$. If it is boiled with a known amount of alkali and back-titrated with acid, however, it behaves as a base if the end point is taken at $(H^+) = 1 \times 10^{-2}$, and as an acid if the end point is taken at $(H^+) = 1 \times 10^{-11}$. What class of substances might behave in this way?

102. A neutral substance which contains only carbon, hydrogen, and oxygen, when heated with alkali, forms an acid but no other substance. The equivalent weight of the acid formed is 18 units greater than the molecular weight of the original substance. What class of substances might behave in this way?

APPENDIX

VAPOR PRESSURE OF WATER IN MILLIMETERS OF MERCURY

DEGREES C.	MILLIMETERS	DEGREES C.	MILLIMETERS	DEGREES C.	MILLIMETERS	DEGREES C.	MILLIMETERS
0	4.6	9	8.6	18	15.5	27	26.7
1	4.9	10	9.2	19	16.5	28	28.4
2	5.3	11	9.8	20	17.5	29	30.1
3	5.7	12	10.5	21	18.7	30	31.8
4	6.1	13	11.2	22	19.8	31	33.7
5	6.5	14	12.0	23	21.1	32	35.7
6	7.0	15	12.8	24	22.4	33	37.7
7	7.5	16	13.6	25	23.8	34	39.9
8	8.0	17	14.5	26	25.2	35	42.2

VAPOR PRESSURES OF ORGANIC LIQUIDS IN CENTIMETERS OF MERCURY

DEGREES C.	CH_3OH	CS_2	CCl_4	$CHCl_3$	C_2H_5OH	$(C_2H_5)_2O$	$(CH_3)_2CO$	C_6H_6
0	2.68	12.79	3.29	5.97	1.27	18.44	—	2.53
5	3.69	16.00	4.32	—	1.76	23.09	—	3.42
10	5.01	19.85	5.60	10.05	2.42	28.68	—	4.52
15	6.71	24.41	7.17	—	3.30	35.36	—	5.89
20	8.87	29.80	9.10	16.05	4.45	43.28	17.96	7.96
25	11.60	36.11	11.43	20.02	5.94	52.59	22.63	9.59
30	15.00	43.46	14.23	24.75	7.85	63.48	28.10	12.02
35	19.20	51.97	17.55	30.35	10.29	76.12	34.52	14.93
40	24.35	61.75	21.48	36.93	13.37	90.70	42.01	18.36
45	30.61	72.95	26.08	44.60	17.22	107.42	50.75	22.41
50	38.17	85.71	31.44	53.50	21.99	126.48	62.29	27.14
55	47.22	100.16	37.63	63.77	27.86	148.11	72.59	32.64
60	57.99	116.45	44.74	75.54	35.02	172.50	86.05	39.01
65	70.73	134.75	52.87	88.97	43.69	199.89	101.43	46.34
70	85.71	155.21	62.11	104.21	54.11	230.49	118.94	54.74
75	103.21	177.99	72.57	121.42	66.55	264.54	138.76	64.32
80	123.85	203.25	84.33	140.76	81.29	302.28	161.10	75.19
85	147.09	231.17	97.51	162.41	98.64	343.95	186.18	87.46
90	174.17	261.91	112.23	186.52	118.93	389.83	214.17	101.27
95	205.17	296.63	128.69	213.28	142.51	440.18	245.28	116.75
100	240.51	332.51	146.71	242.85	169.75	495.33	279.73	134.01

TABLE OF THE CHEMICAL ELEMENTS, INCLUDING THEIR SYMBOLS, THEIR ATOMIC NUMBERS, AND THEIR ATOMIC WEIGHTS

NAME	SYMBOL	ATOMIC NUMBER	ATOMIC WEIGHT	NAME	SYMBOL	ATOMIC NUMBER	ATOMIC WEIGHT
Actinium	Ac	89	—	Mercury	Hg	80	200.61
Aluminum	Al	13	26.97	Molybdenum	Mo	42	96.0
Antimony	Sb	51	121.77	Neodymium	Nd	60	144.27
Argon	A	18	39.91	Neon	Ne	10	20.2
Arsenic	As	33	74.96	Nickel	Ni	28	58.69
Barium	Ba	56	137.37	Nitrogen	N	7	14.008
Beryllium	Be	4	9.02	Osmium	Os	76	190.8
Bismuth	Bi	83	209.00	Oxygen	O	8	16.000
Boron	B	5	10.82	Palladium	Pd	46	106.7
Bromine	Br	35	79.916	Phosphorus	P	15	31.027
Cadmium	Cd	48	112.41	Platinum	Pt	78	195.23
Calcium	Ca	20	40.07	Polonium	Po	84	210.(?)
Carbon	C	6	12.000	Potassium	K	19	39.096
Cerium	Ce	58	140.25	Praseodymium	Pr	59	140.92
Cesium	Cs	55	132.81	Protoactinium	Pa	91	—
Chlorine	Cl	17	35.457	Radium	Ra	88	225.95
Chromium	Cr	24	52.01	Radon	Rn	86	222.
Cobalt	Co	27	58.94	Rhenium (?)	Re	75	—
Columbium	Cb	41	93.1	Rhodium	Rh	45	102.91
Copper	Cu	29	63.57	Rubidium	Rb	37	85.44
Dysprosium	Dy	66	162.52	Ruthenium	Ru	44	101.7
Erbium	Er	68	167.7	Samarium	Sm	62	150.43
Europium	Eu	63	152.0	Scandium	Sc	21	45.10
Fluorine	F	9	19.00	Selenium	Se	34	79.2
Gadolinium	Gd	64	157.26	Silicon	Si	14	28.06
Gallium	Ga	31	69.72	Silver	Ag	47	107.880
Germanium	Ge	32	72.60	Sodium	Na	11	22.997
Gold	Au	79	197.2	Strontium	Sr	38	87.63
Hafnium	Hf	72	178.6	Sulfur	S	16	32.064
Helium	He	2	4.00	Tantalum	Ta	73	181.5
Holmium	Ho	67	163.4	Tellurium	Te	52	127.5
Hydrogen	H	1	1.008	Terbium	Tb	65	159.2
Illinium	Il	61	—	Thallium	Tl	81	204.39
Indium	In	49	114.8	Thorium	Th	90	232.15
Iodine	I	53	126.932	Thulium	Tm	69	169.4
Iridium	Ir	77	193.1	Tin	Sn	50	118.70
Iron	Fe	26	55.84	Titanium	Ti	22	48.1
Krypton	Kr	36	82.9	Tungsten	W	74	184.0
Lanthanum	La	57	138.90	Uranium	U	92	238.17
Lead	Pb	82	207.20	Vanadium	V	23	50.96
Lithium	Li	3	6.940	Xenon	Xe	54	130.2
Lutecium	Lu	71	175.0	Ytterbium	Yb	70	173.6
Magnesium	Mg	12	24.32	Yttrium	Y	39	88.9
Manganese	Mn	25	54.93	Zinc	Zn	30	65.38
Masurium (?)	Ma	43	—	Zirconium	Zr	40	91.

AQUEOUS VAPOR PRESSURE OF POTASSIUM HYDROXIDE SOLUTIONS IN MILLIMETERS OF MERCURY

DEGREES C.	CONCENTRATION IN GRAMS OF KOH PER 100 GRAMS OF SOLUTION			
	23.1	28.6	32.9	40*
10	7.3	6.5	5.6	3.7
12	8.4	7.5	6.4	4.3
14.5	9.8	8.7	7.6	5.0
16	10.8	9.6	8.3	5.5
18	12.3	10.9	9.5	6.2
20	13.9	12.4	10.7	7.2
22	15.7	14.0	12.2	8.3
24	17.8	15.9	13.8	9.6

INDICATORS AND REAGENTS

Congo red. Dissolve 5.0 g. of Congo red in 1000 cc. of a 10 per cent solution of alcohol in water.

Litmus solution. Pour 500 cc. of boiling water over about 40 g. of litmus cubes and allow the mixture to stand for an hour. Then filter the solution. Repeat the process with another 500 cc. of boiling water on the undissolved residue of the litmus cubes and mix the two solutions.

Methyl orange. Dissolve 1.0 g. of methyl orange in 500 cc. of alcohol and add enough water to make the volume of the solution 1000 cc.

Methyl red. Dissolve 1.0 g. of methyl red in 1000 cc. of 50 per cent alcohol.

Methyl violet. Dissolve 1.0 g. of methyl violet in 1000 cc. of water.

Phenolphthalein. Dissolve 1 g. of phenolphthalein in 1000 cc. of 70 per cent alcohol.

Starch solution. Make a paste of 5.0 g. of starch in 50 cc. of cold water. Pour this paste into 1000 cc. of boiling water. Stir and boil the mixture for a few minutes, and then filter it.

Starch iodide solution. Dissolve 50.0 g. of potassium iodide in 1000 cc. of starch solution in the cold. Starch iodide paper may be prepared by saturating strips of filter paper with this solution and allowing them to dry.

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* The data for this table were taken from the Chemiker Kalender (Berlin, 1924), with the exception of the last column. The values for the vapor pressure of the 40 per cent solution were obtained by a graphical extrapolation of the other data and are accurate to within ± 0.5 mm.

Fehling's solution. This solution is prepared and kept as two separate solutions, which are mixed in equal volumes just before using. One solution is made by dissolving 69.0 g. of copper sulphate in 1000 cc. of water, and the other by dissolving 346.0 g. of sodium potassium tartrate (Rochelle salt) and 100.0 g. of sodium hydroxide in 1000 cc. of water.

Iodine in potassium iodide solution. Dissolve 12.7 g. of iodine in 1000 cc. of a 2 per cent solution of potassium iodide in water.

Molisch's reagent. Dissolve 3.0 g. of α-naphthol in 25 cc. of alcohol.

Molybdate solution. Mix 72 cc. of aqueous ammonia (sp. gr. 0.98) with 135 cc. of water. Dissolve 50 g. of molybdic acid in this solution. Pour the resulting ammonium molybdate slowly, and with constant stirring, into a nitric acid solution containing 245 cc. of nitric acid (sp. gr. 1.42) and 574 cc. of water. Allow the mixture to stand for several days (until a test portion heated to 40° C. yields no precipitate of ammonium phosphomolybdate). Decant the clear solution from any sediment in the container and keep it in glass-stoppered bottles.

Potassium permanganate solution for absorption of nitric oxide. Dissolve 50.0 g. of potassium permanganate and 25.0 g. of potassium hydroxide in 1000 cc. of water.

Schiff's reagent. Dissolve 0.5 g. of magenta in 500 cc. of distilled water. Pass sulphur dioxide gas into the solution until the color of the dye is discharged.

Sodium amalgam. Place a weighed quantity of mercury (200 or 250 g.) in a dry evaporating dish and warm it to 75° or 80°. Weigh out a quantity of clean, dry, freshly cut sodium equal to 3 per cent of the weight of the mercury. Cut the sodium into thin slices. Drop it, one slice at a time, on the surface of the mercury and immediately force it below the surface of the mercury by means of a pestle. In performing this operation be sure to protect the eyes with goggles and to wrap the hands in towels. The sodium sometimes spatters, and small burning particles are thrown in all directions. Unless the process is carried out rapidly the amalgam may solidify before all the sodium has been dissolved. Break up the solid amalgam and keep it in a dry glass-stoppered bottle until wanted.

Tollen's reagent. Add 2 drops of 12 N sodium hydroxide to 10 cc. of 0.1 N silver nitrate. Then add 12 N ammonium hydroxide until the precipitated silver oxide is dissolved. This solution should not be kept in stock, as it slowly precipitates a dangerously explosive silver compound.

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